DENTAL ELECTRICITY

By

LEVITT E. CUSTER, B.S., D.D.S.

Lecturer upon
Dental Electricity in Ohio College of Dental Surgery;
Member of National Dental Association;
Member of Ohio State Dental Society;
Member of New York Institute of Stomatology;
Honorary Member of
Kansas State Dental Society;
Corresponding Member of Illinois State
Dental Society;
Member of Roentgen Society of the
United States;
Etc.

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PREFACE

FOLLOWING the usual custom in a few prefatory remarks, not that they are ever read, the author would take this opportunity of saying that in preparing this volume he has had in mind the busy life of the dentist and the aim has been to present the subject in the most tangible manner. Up to this time there is no single work to which the dentist might refer for information upon the electrical questions with which he has to deal, without going over much that is foreign to the subject. To this end many personal experiments have been performed, in some cases to verify certain existing opinions, and in others to adapt some appliance to the dentist's use. An independent plant was established for two purposes; one for the carrying out of the necessary experiments, and the other for the purpose of determining the feasibility, and the requirements that would be necessary for the establishing of an independent plant for the dentist who has not access to a commercial current.

The author does not presume to present anything new upon the fundamental subjects, the nature of electricity, magnetism, etc., but rather in as concise a manner as possible to put them before the reader as a resumé. All technical terms are avoided save a few without which even a cursory study of electricity would be wanting. L. E. C.

Dayton, Ohio.

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INTRODUCTION

Electricity in Dental Practice.

No profession or art has such varied demands for its successful practice as dentistry, and no single agent meets more of these requirements than electricity as at present developed.

In the past the only practicable applications of electricity were such as could be derived from battery power, but the output of the battery as a source of electric energy was so small as compared with its bulk that even the space it occupied was no small consideration. The care necessary to keep it in good working order was a burden, and the great complication of the parts made electricity a formidable and uncertain agent. On this account, if the dentist used electricity at all, his battery consisted of but a few cells, and he was content to use only such instruments as required but little electric energy to operate them. In fact the first applications of electricity were in the form of light power such as would operate the armature in the shocking machine or, later on, the electric mallet, cautery, and mouth lamp. Although the battery, as a source of electric energy, was practical and successful in the hands of a few who understood it, it has not proven so in the hands of the majority, and this has cast a shadow upon the advent of commercial electricity as supplied to us at this day. Many, no doubt, have hesitated to install modern electricity in their practice for no other reason than that it has not been a brilliant success as supplied by the battery power of the past. But the beginner should bear in mind that he has no longer to do with the making of the energy, but with the use of it as furnished to him by two or three wires. The generating of commercial electricity has become an industry engaged in by

corporations and companies for the supply of cities and towns, and the operation of an electric plant on a small scale has been made so simple that many public buildings, hotels, and private residences operate their own.

While we cannot yet say with certainty what electricity is, it has been found, however, to produce results as accurate as those obtained by the application of a rule in mathematics, and when it is properly understood it can be depended upon. A given current forced through a known conductor under a given pressure always produces the same amount of magnetism in an iron core, the same rise in temperature in the conductor, or deposits the same quantity of a metal from its solution. A current of 7.46 amperes flowing under one hundred volts' pressure is a force equal to one horse-power. The heat produced by burning a given quantity of ethyl alcohol can be quite closely calculated, but not so easily or accurately as the heat produced by electrically heating a conductor. It is possible for the electrician to figure with pencil and paper beforehand the exact amount of heat that will be produced by the various arrangements of quantity, pressure, and resistance; or, a given current, it has been found, will deposit a given quantity of metal from its solution in a certain time. One ampere will deposit 4.024 grammes of silver in one hour.

These results always follow the operations of electrical energy and are so accurate and ever present that they are made the basis for the measurement of electricity. The different forms of the voltmeter, ammeter, and wattmeter are constructed so as to operate under one of these laws, or a combination of them. In the electro-magnetic meter the current is measured by the electro-magnetic effects; in the electro-thermal meter, by the increase in the temperature of a resistance through which the current passes, or by the evaporation of a liquid heated by the current; or in the electro-chemical, by the electrolysis of the solution of a metallic salt, the deposit being weighed.

Nearly all operations in dental practice require the utmost accuracy in the application of energy whether in the form of power, heat, light, or chemism, and as seen from the foregoing, the principal of the characteristics of electricity is the identity of its operations under like conditions. Not only that, but the perfection and ease with which its action may be regulated or varied for different degrees of intensity are important considerations. The speed for revolving the bur, the heat for the dessication of dentine, for softening gutta-percha, for annealing gold, or for fusing porcelain should be easily varied to suit each case at hand. These conditions are not always alike, and electricity obeys the throw of the rheostat lever so accurately that, as if by magic, the will of the operator is felt at the instrument under operation. After a little experience, his control over each appliance through the rheostat becomes almost automatic. The pianist in reading a piece of music, does not think of the movement of each of her fingers as they glide over the fingerboard, or of the management of the pedals with her feet, and so it is in the manipulation of a well-constructed electrical instrument. There is no effort at calculating how a certain thing is to be accomplished, but quite involuntarily the mental image of what is to be done is transformed into the deed itself. The electric dental engine as perfected to-day increases or decreases its speed, stops or reverses at the touch of the operator, and all this is so easily done that after a little use it requires no great effort on his part. The mental routine ceases and the control becomes automatic. The attention of the operator, instead of being divided between instrument and operation, is now concentrated upon the latter.

The pressure of commercial current as used for incandescent lighting is practically steady so that each contact button of the rheostat always gives the same rate of speed to the engine, or the same heat to the heating appliances, and by a glance at the rheostat the rate of current flow is noted.

Or, a predetermined requirement of energy for a given purpose or instrument can always be accurately obtained thereafter by using the same contact button. The flow of water from a faucet or of gas from a burner cannot be more accurately regulated than a current of electricity by means of the rheostat. The great variety of appliances that can be made for modifying the transit of the electric current, the accuracy of their gradations and perfection of control at once make it possible to use the same current for the heaviest motor work or the most delicate cataphoresis. No energy at our command has such a wide range of action and is at the same time so easily and accurately regulated as electricity.

The cleanliness of electricity is another prominent characteristic, and this is especially desirable in dental practice. The older forms of power, except foot-power, when used at all, were obtained by the combustion of oil or gas, or by the use of a water-motor. While the gas-engines were generally satisfactory, the odor of the oil or gas would in time fill the apartment, and the complication of parts was sometimes a source of trouble. The water-motor was cleaner but water-power was not always available. The one thing prominent in the use of electric energy is the cleanliness that may be preserved in whatever form it is used. Wherever there is friction in machinery there must be a lubricant, and wherever there are many moving parts the difficulty of preserving cleanliness is often serious. In the electric motor the two bearings of the armature shaft are the only parts that require oil, and, since the motion here is rotary, there is little danger of the oil being thrown about. In well-constructed motors the bearings are not only continuously oiled either by a revolving ring or by a wick, but the whole bearing is so constructed that the surplus oil finds its way into a drip-cup. An eighth horse-power motor can be placed at any convenient point about the chair without any danger of soiling the immediate objects.

The electric light has advantages over other forms. It, too, is without dirt or odor. The atmosphere is not robbed of its oxygen, nor is it vitiated by the products of combustion. A small light can be enclosed within the mouth without discomfort, or a large one may be poised in any desired position about the chair. The heat radiated from the incandescent bulb is not enough to set fire to objects with which it may come in contact, so that it can often be used where a gas or oil flame would not be permissible.

While the cleanliness of electrical heat would alone recommend it for use in the dental office, there are some processes in dental practice to which electrical heat by its purity and wide range is especially adapted, as for instance, its purity for annealing gold, or fusing porcelain, or its wide range, from the softening of gutta-percha or warming water, to the melting of porcelain and platinum. Pure heat is of solar origin, and yet when heat is produced by electrically heating a conductor which does not oxidize, or undergo any change, as is the case with one constructed of platinum or iridium, it is practically pure. It is without gas or odor and can be easily regulated. The range of electrical heat depends upon the manner in which it is produced. If it is produced by the resistance of the conductor, then the highest limit of the heat will be the melting-point of that conductor. If platinum or iridium be used as the conductor the range of heat will be between zero and the melting-points of these metals, or about three thousand six hundred degrees. If it is the heat of the arc it will be nearly six thousand degrees Fahr. While the latter is the most intense heat that man can produce, it can at the same time be manipulated between the two hands of the operator without inconvenience or danger to life, again illustrating the fitness of electricity for dental practice.

A feature characteristic of electric energy is the very small amount of noise in its operations. As a matter of fact, there is no noise in any operation of electricity itself when prop-

erly used except the arc tone or the sharp report following a voltaic discharge. The sputtering of the arc light is due to bad carbons or imperfect adjustments, and the noise of the motor is due more often to badly shaped armatures and poor adjustment of the brushes than to the flow of the current. These are the faults of the instruments themselves and not of the energy which operates them. But even a bad electric-motor produces no more noise than the very best water-motor of the same horse-power. The engines operated by gas, oil, or steam are ordinarily reciprocating engines; and wherever there is a change in the direction of the movement of any mass of metal, as there is in the pistons and valves of these engines, vibrations will be set up in the whole machine and in adjoining objects which produce the noise and jar characteristic of these engines. With the electric-motor, however, the motion is rotary, and the only sound from a good instrument is the hum produced by the air friction of the armature, or perhaps the friction of the brushes upon the commutator. The noise of the electric mallet is due to the weighted armature coming abruptly against hard substances in either direction of its swing. But since the force of each blow depends upon the sudden impact of one moving mass against another, the sound thereby produced will always be present. It is in the nature of things.

The other operations of electric energy are without any audible sound. An oven may be heated to the melting point of platinum and there may be a horse-power of energy in operation, but it cannot be heard. The incandescent light glows and all galvanic processes go on without sound.

When the dental office is equipped with commercial electricity as at present supplied, the current becomes as reliable as the water or gas, and the dentist is relieved of much care. Then, too, the instruments for using the current are highly perfected. The current is supplied at a given pressure which is maintained at all times with wonderful accuracy. The instruments using it are made to operate with

this pressure just as a gas-burner for gas, or a water-motor for water. With an electric system operating at one hundred and ten volts' pressure, a lamp when burning plainly shows a departure of five volts in either way from the standard. For this reason the operator need not at any time be concerned about the working of his electrical instruments when they are used upon the current for which they are intended. His supply is always uniform, and he needs only see that the connections are properly made. The electric light requires no care to keep it in order, and the motor needs only to be kept clean and oiled occasionally. The heating appliances require no especial attention and the other operations of electricity go on with like freedom from care on the part of the operator.

Another feature which commends the use of electricity in dental practice is the flexibility of the system. Wherever water is used in an office it is necessary to convey it by a system of piping. This not only necessitates lifting the floors or plastering, but the danger of leaks occurring at points difficult of access is always present. Any additional fixtures require great expense and discomfort if the pipes are concealed. The same that is said of water piping applies also to gas-fixtures.

If water is used for power, the customary method of transmitting the power from the motor to the lathes is by a system of shafting, so that it is not easy to extend it to adjoining rooms, or to any great distance. When a single motor is used for all purposes as is generally the case where water-power is used, it is often necessary to set the whole line of shafting in operation for the smallest as well as the largest piece of work. With the electric system, however, it is quite different. Any change or extension of the electric wiring of the apartment is much more easily made than in the case of pipes. Instead of lifting the floors and plastering for this purpose, the wires can often be laid or pushed through between the floors or walls. The manufacturers have produced so many convenient appliances for outside or open wiring

that it is not always necessary to conceal the wires. They have also simplified matters by the use of the flexible cord so that a motor, lamp, or any instrument or appliance can be quickly attached to a fixture and placed at will. The electric fan can be attached to a lamp socket and placed in any suitable position with no further trouble than that of screwing in the plug. For lathe work, instead of having one large motor, as is necessary when using water-power or the gas-engine, several motors may be used, each one adapted and belted for the particular use for which it is intended. Thus one for grinding and polishing in the laboratory, one for condensing air, and one for the operating chair is a luxury not realized from any other form of power.

For a time after the introduction of electricity, there were many death accidents from this agent. This has led to the belief that the dentist would endanger his life by using electricity in any other form than that for which it is commonly used,—light and power. But he should bear in mind that all the practical uses to which he can put it do not require a high voltage, and the currents ordinarily employed for incandescent lighting meet every requirement. The pressure of these currents does not exceed two hundred and twenty volts, and while some persons, under favorable conditions might be unpleasantly shocked by this current it is not regarded as a dangerous one. But a current of two hundred and twenty volts is not ordinarily used for lighting. In the three-wire system it can be obtained by connecting the outer wires, but the lamps are usually placed between one of the outer wires and the middle wire which gives but half of two hundred and twenty, or one hundred and ten volts. In the ordinary wiring of buildings it would be by accident entirely, that a person would make contact between the outer wires and receive two hundred and twenty volts. When the alternating current is used the voltage is often as low as forty-eight.

Currents of over two hundred and twenty volts' pressure

are not only dangerous to life, but they possess no practical value over lower voltage currents for dental purposes. The five hundred volt current may be used for power, light, or heat, where the lower pressure currents are not available, but this is regarded a dangerous current since there have been deaths from it under favorable conditions, and the dentist should protect himself by means of automatic appliances which make it an impossibility to get the full current strength through thoughtlessness on his part.

DENTAL ELECTRICITY.

CHAPTER I.

Nature of Electricity.

There is no generally accepted theory as to the nature of electricity. By some it is regarded as a property of all matter, some have thought it to be vibratory molecular motion, some a fluid, some two fluids, some a motion in the ether, and some the ether itself. We can only study it comparatively. The resemblance of its phenomena to those of heat and light place it in that class of energy. Heat, light, and electricity may be derived from friction, from chemical action, from magnetic action, and from the sun. Heat produces electricity, and electricity produces heat. If the junction of a thermopile be heated a difference of potential will be established; or, if a current is passed through the couplet the junction will become heated. A crystal of tourmaline and many other crystalline bodies when heated at one end show a difference of potential. Electricity also produces light and will neutralize the polarizing effect of light. Hence, from the facts well known as to the nature of heat and light and their reciprocal action with electricity, we may infer many of the facts in regard to the nature of electricity.

Heat and light are each regarded as a mode of molecular motion, and while electrical phenomena are of greater variety and oftentimes present themselves in complicated forms, yet all these when simplified and understood show that the electrical phenomena are due to a molecular energy not unlike heat and light.

Heat was shown by Davy to be a form of motion in matter and has been so accepted. This motion has been further shown to be vibratory. Heat is transmitted through substances by *conduction*. In this the molecules are set into vibrations according to the degree of heat, and those substances whose molecules can most easily and quickly assume this molecular agitation are called good conductors and those which do not possess this property are called poor conductors. It would be fair to suppose that, if, as a rule, all those substances which are conductors of heat are found to be conductors of electricity in a similar degree, the two energizing forces, heat and electricity, would be very similar forms of motion. And so it is found; the degree of conductivity for heat and electricity is nearly the same in the same substances. A good conductor of heat is also a good conductor of electricity, and a poor conductor of heat is also a poor conductor of electricity. This remarkable fact is shown in the table on the following page by Wiedmann and Franz, and it will be observed upon an inspection of the two columns that there are three metals, silver, german silver, and bismuth, whose conductivity of heat and electricity is precisely the same.

The two columns are so nearly alike that it cannot be regarded simply as a coincidence, and we are warranted in ascribing a similarity to the two, and in assuming that electricity traverses these substances by a mode of motion not unlike that of heat.

Substance.	*Heat Conductivity.*	*Electric Conductivity.*
Silver	100	100
Copper	74	73
Gold	53	59
Brass	24	22
Tin	15	23
Iron	12	13
Lead	9	11
Platinum	8	10
German Silver	6	6
Bismuth	2	2

Light was shown by Fizeau to be a form of motion in ether, and this form of motion has been supposed to be undulatory. It is propagated through the ether in waves similar to the movement of a taut rope when struck. Light will produce electricity and electricity will produce light. A clean metallic plate will become electrified when light falls upon it; or if the two electrodes of a selenium cell be unequally illuminated, a difference of potential will be produced.

This reciprocal action between electricity, heat, and light is almost conclusive proof of the theory that electricity is a mode of motion similar to heat and light.

In the various applications of electricity, such as the

telegraph, the telephone, electroplating, and in the operation of machinery by the electric motor, it is called the *electric current.* We imply that the electricity is flowing and we, in a measure, think of it independently of its conductor. But, as a matter of fact, we are not sure of the direction in which it flows, or whether or not it flows at all. Many phenomena, however, indicate that it has motion, and it is generally so regarded. In electrolysis there is a transfer of molecules and atoms, and in the electric arc we have a phenomenon which very clearly shows that it travels from one pole to the other.

VARIETIES OF ELECTRIC CURRENTS.

Electric currents may be divided into four general classes: the *continuous* current, *pulsating* current, *interrupted* current, and *alternating* current.

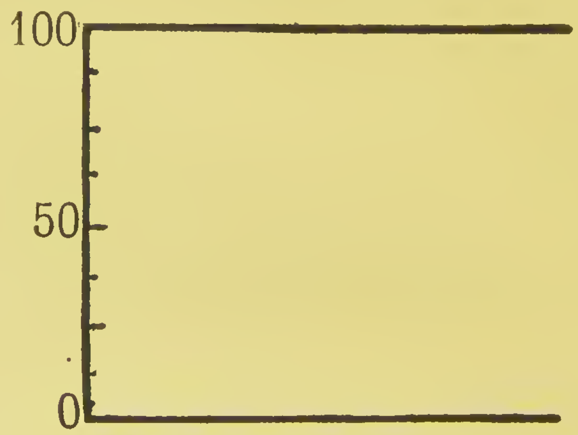

FIG. 1.—CONTINUOUS CURRENT.

The continuous current is one in which the electricity is presumed to flow in one direction at a uniform rate. In this the pressure is very evenly maintained.

The most regular continuous current is supplied by the thermopile, the voltaic and storage cells. The continuous-current dynamo as at present perfected also supplies a practically steady continuous current. This current is especially adapted for electrolytic and cataphoric work. In electrolysis the object is to decompose the electrolyte and separate the elements according to their electric affinity, the electro-positive element or elements being found at the negative pole and the electro-negative at the positive pole. If the current were alternating, the poles of the electrode would be constantly changing so that there would be alternate deposition and solution of the elements of the electrolyte, and conse-

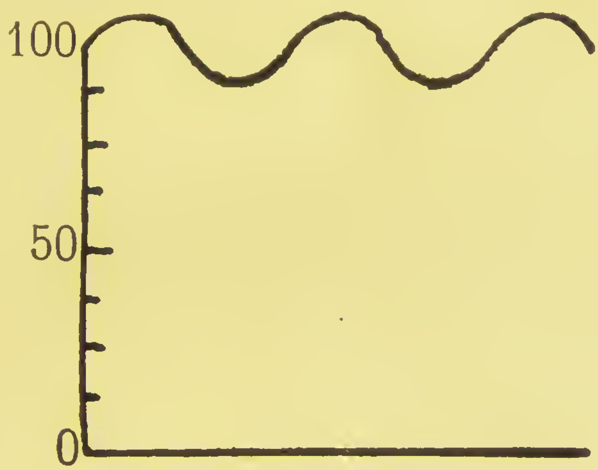

FIG. 2.—PULSATING CURRENT.

quently no permanent deposition of any element. In cataphoresis the object is to project an agent into underlying tissue. Since the agent is carried in with the current, it is apparent that the current must always flow in that direction. The amount which would be

deposited by the current flowing in one direction would be carried out upon its reversal, if an alternating current were used.

The pulsating current flows in one direction at all times but at a variable pressure. This current is produced by nearly all dynamo-electric machines.

In some cases the pulsations are so slight that their effect is scarcely noticeable when the current is used for lighting or plating. Such a current may be regarded as practically continuous, but when used in

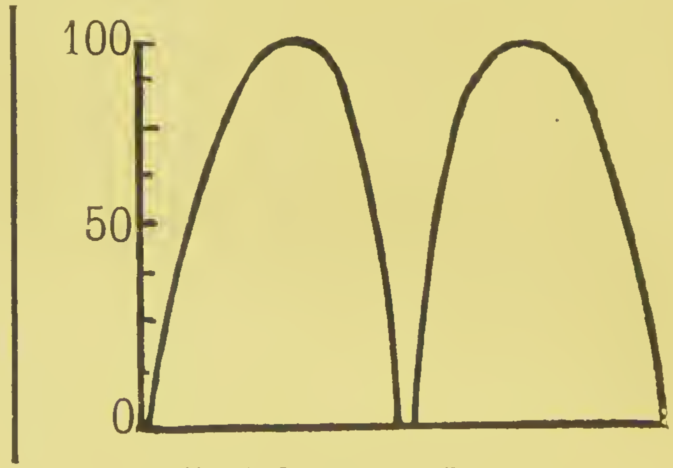

FIG. 3.—INTERRUPTED CURRENT.

electro-therapeutics or for cataphoresis the pulsations are sometimes quite noticeable.

The interrupted current is one which flows in one direction when in motion but which is completely arrested at frequently recurring intervals.

The continuous current flows at the same rate at all times, and the pulsating current flows at an uneven rate. In neither case does the flow stop, but the interrupted current is completely stopped or arrested. This cur-

rent is used in telegraphy and in electrotherapeutics under the name of Faradic current and is the one used in shocking machines.

The alternating current is one in which the electricity flows alternately in one direction and then in the other.

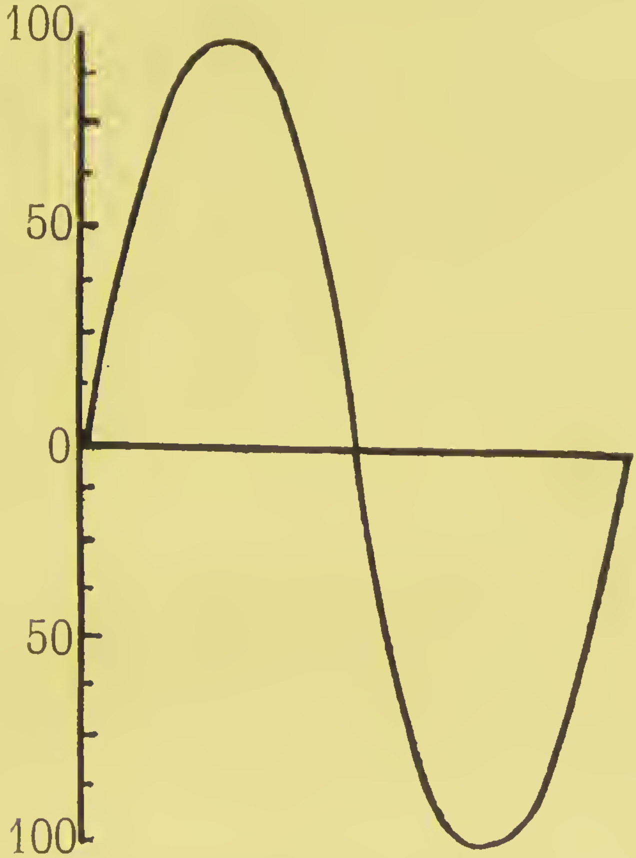

FIG. 4.—ALTERNATING CURRENT.

Here we have not only a break in the flow of the current, but a flow in the opposite direction.

The alternating current is very useful from the fact that it can be transformed and thereby changed to a higher or lower voltage. This current is principally used for lighting and power.

In classifying electric currents into these four varieties, it should not be inferred that every electrical impulse or current would give a curve like one or the other of these if diagrammatically represented. There are some currents which partake of the nature of two to such an extent that if diagrammed it would be difficult to determine to which class they belong. Then again, as an illustration, an alternating current may be so smooth in its reversals that it will give quite a different effect from that of a commercial alternating current when used in electrotherapeutics. Such a current is technically known as a *sinusoidal* current. This is an alternating current, and yet its change of direction is so smoothly accomplished that it possesses a property of distinct value in electrotherapeutics.

CHAPTER II.

Electrical Terms.

Electricity has a nomenclature peculiar to itself, and it differs from most sciences in that its terms are nearly all derived from proper names; or, in other words, the name of the person who discovered a certain law in electricity is used as the electrical term for that law. The term "volt," the unit of electromotive force, was named after Alexander Volta, who invented the voltaic pile. The ampere, the unit of electric current, was named after Ampère, the French physicist. The ohm, the unit of electric resistance, takes its name from Dr. George Ohm, who published the well-known law that bears his name. And so with many others. The watt, the farad, the joule, or the coulomb are all derived from proper names.

POTENTIAL.

The term *potential* is a relative one and is used to denote the capacity for doing work. Electric potential can be best understood if we compare it with water. Water flows through a pipe because one end of the pipe is lower than the other, and by the laws of hydrostatics, work will be done according to the quantity of water and the difference of elevation between the upper and lower levels. Electric potential may be said to be electric level, and in the same way we may consider electric potential to be the ability to do work. The work done depends upon the quantity of electricity and the differ-

ence of potential. When water flows straight down from the higher to the lower level, the full pressure may be utilized at the opening, but if the water passes through a great length of pipe, then there is a loss due to friction. This is diagrammatically shown in Fig. 5.

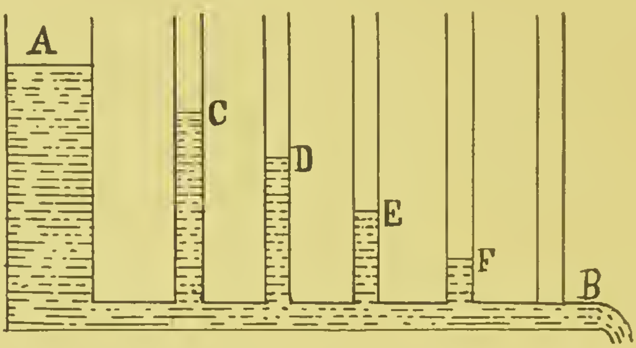

FIG. 5.—HYDRAULIC GRADIENT.

The quantity of water that flows through a pipe is the same at all places in the pipe, but the pipe offers more or less resistance, and at points distant from the source the pressure is less than at points on the same level near the source. This difference of pressure is due to the friction of the pipe and is analogous to the resistance of electrical conductors. The pressure per square inch in the pipe decreases proportionately to the distance from the source. If the opening B in Fig. 5 be closed the water will rise to the same level in the tubes C, D, E, and F. But if B be opened then the water in the tubes will assume various levels as represented. The pressure from the tank A is felt more at C than at F and for that reason the water assumes different levels. If a line be drawn from A to B it will tell the height to which water will rise at any given

point. When an opening is made at B the pressure in pipe F is greater than through the supply-pipe at B, because of the distance from the source. The water in pipe F, therefore, quickly drops to a point where it is balanced by the pressure in the supply pipe.

In like manner we may consider electricity. The dynamo raises the potential to a given level, and if the current flows back to the dynamo through a short and

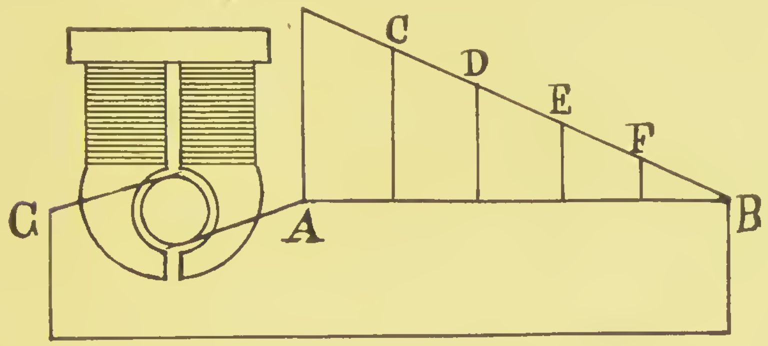

Fig. 6.—Fall of Electrical Potential.

thick conductor the full potential is operative, but if the current be lead through a great length of wire, the difference of potential is less than through a short wire. The working capacity is greatest at the dynamo because the greatest difference in potential exists at that point, and there is a decrease of potential proportionate to the distance from the dynamo. The fall of electrical potential is shown in Fig. 6. The dynamo creates potential the pressure of which is represented by the vertical line at A. If A and G were connected by a short piece of stout wire the full pressure would be felt, but if the current is caused to travel to B and then return, the potential at various distances from the dynamo

would be represented by the vertical lines, C, D, E, and F. There is a continual drop in the potential which is proportionate to the distance from the dynamo.

This, like the loss of pressure in water, is due to resistance. In the case of water it is due to the resistance of the pipe and in the case of electricity it is due to resistance of the wire.

All electrical phenomena are due to difference in potential, and the movement from a higher to a lower, or the neutralizing of the positive and the negative if you will, represents electricity at work. The motor runs, or the electrolyte is decomposed by the difference of potential existing at the extremities of the conductor and the effort of this difference to become balanced.

THE VOLT.

The action of the dynamo, the battery, or the thermopile is to create a difference of potential, so that if a path is made for the current to traverse, it will do work or overcome resistance, and will flow from the higher to the lower according to the pressure. Now the pressure which this difference of potential produces, or the tension which the current is under in its strained condition, or the capacity of the fluid for overcoming resistance, if you will, is the *volt.*

This term is analogous to the term "pressure" in hydrostatics. In fact, the flow of water in a pipe, and electricity in a conductor are so nearly alike in their various laws and phenomena that the term "pressure" which more properly applies to the water, is often used instead of the word "volt" in electricity. We speak

of 52 volts, 110 volts, or 500 volts just as we would of water under say, 52, 110, or 500 pounds' pressure. Fifty-two volts will carry a given current through ten feet of wire, or fifty-two pounds' pressure will lift water to a height of ninety-seven feet; but one hundred and four volts will carry the same current through twice that length of wire. It requires about forty-five volts to maintain the arc in the arc-light and for every lamp added there must be an increase of forty-five volts. It requires less wire to go from one lamp to the other successively than it does to run separate wires from the dynamo to each lamp, so that as a matter of economy it is usual to connect these lamps in series, beginning at the dynamo, running through fifty or one hundred arc lamps successively, and returning to the dynamo. Now since it requires forty-five volts to jump the arc in one lamp, if there are fifty lamps on the circuit it would require 50 times 45, or 2,250 volts to maintain the arcs of a fifty-lamp circuit. To this must be added the voltage necessary to overcome the resistance of the wire from lamp to lamp, the total of which is from fifty to two hundred volts according to the size and length of the conducting wire. The Edison current is usually operated at one hundred and ten volts' pressure. This will bring to full candle power a carbon filament five one-thousandths of an inch in diameter and six inches in length, but a current of five hundred and fifty volts which is sometimes used on street railways will bring to full candle power five such lamps if placed in series, one after the other. In the latter case thirty inches of filament are brought to incandescence because the cur-

rent of five hundred and fifty volts can overcome five times the resistance that can be overcome by one hundred and ten volts.

A difference of potential being created by a battery or dynamo, the current is carried or propelled through a conductor by a pressure which, as stated, is termed the volt. Where this is considered in relation to current and resistance it is the active force, (sometimes called electromotive force and abbreviated E. M. F.,) the current is the active agent, and the resistance is the object or part acted upon. The relation of voltage to current and resistance is always constant. This discovery was made by Doctor Ohm in 1827 and has since been known as Ohm's law. It is expressed as follows: *The current strength in any circuit is equal to the electromotive force divided by the resistance.*

This is usually written: $C = \frac{E}{R}$

In this formula, C represents the current strength in amperes, E the electromotive force in volts, and R the resistance in ohms. By substituting the name for the abbreviation we have: The amperes $= \frac{\text{the volts.}}{\text{the resistance.}}$ The equation may be transposed so as to give us the value of the volt in relation to current and resistance and when so transposed would read: $E = C \times R$.

If we know the values of C and R, that of E can be easily found. Thus, if a current of ten amperes is flowing through a resistance of eleven ohms the equation would read: $E = 10 \times 11 = 110$.

This is the number of volts which would be required

to force ten amperes through eleven ohms' resistance. Or, it may be required to find the electromotive force of a battery whose internal resistance is two ohms and which gives a current of three amperes through a conductor of two ohms' resistance.

The solution, following the equation $E = C \times R$ would be: $E = 3 \times 2 + 2$, or 8 volts.

And so we may go on indefinitely. The laws of current flow are always the same, and again and again through seventy years the law laid down by Ohm has been verified.

THE AMPERE.

A current of electricity possesses a difference of volume as well as a difference of pressure. There may be a current scarcely measurable with the most delicate instruments, or there may be one sufficient to melt an iron rod a foot in thickness and both be under the same pressure. When a stream of water flows from a pipe it is easy to mentally measure its volume. This is because we can see the water and are familiar with its common properties. It is something which is tangible to our senses. But with electricity which we cannot see, and which under some conditions we cannot feel, and which does not emit odor or produce sound, it is quite different. All electrical phenomena take place without the agent's disclosing its identity. All we see is the results of an active, invisible, and imponderable energy. It is for this reason that it is difficult to comprehend that electricity possesses a volume or quantity of current to that extent that it is measurable. But intangible as this agent is, it operates in currents which

vary in volume as much as a stream of water or gas, and the term used in electricity for describing the strength or volume of current flowing is the *ampere.*

We speak of an ampere of current just as we would speak of gas or water flowing from an opening. A gas tip is called a two or four-foot burner, in just the same sense as we would speak of a two-ampere incandescent lamp, and the candle power of either light is increased in precisely the same way.

By increasing the pressure upon the gasometer the quantity of gas escaping from the tip is increased and in like manner by increasing the voltage or pressure of the current the amperes flowing through the filament are also increased. A sixteen candle-power lamp requires about half an ampere at one hundred and ten volts' pressure to bring it to full candle power, while a thirty-two candle-power lamp having a larger filament requires twice that, or one ampere.

The ampere might be said to be the active agent in electricity. It is the working principle. It is that which produces heat, electrolysis, and magnetism. We may say it is electricity itself and not be in error. It is present in all manifestations.

The ampere is of no value, however, unless it is in motion, and the measure of that force which puts it in motion is, as has been stated, the volt. The dynamo at the power-house is forcing the amperes in the conductors under one hundred and ten volts' pressure. During the passage of the amperes of current through the carbon filament, the latter is heated to incandescence; the volts are active at the dynamo and the amperes at

the filament. There can be no electrical work done without the ampere. It may be that less than a thousandth of an ampere is needed in dentine cataphoresis, yet it is upon the current in parts of an ampere that cataphoresis depends. There may be a thousand volts between the poles but if the resistance is so great that no current in amperes can flow, nothing will be accomplished. Tesla has shown that a person can receive fifty thousand volts with no inconvenience. That is because the ampere strength of that current is so infinitely small. A person may touch a trolley wire with the tip of his finger if it is dry, and not be injured by the current, because while the five hundred volts may be operative, the resistance of the dry epithelium is so great that scarcely any current in amperes can be carried with the high voltage. In an electrocution there must not only be volts to overcome the resistance of the human body and carry the amperes through it, but there must be enough current in amperes to produce the electrolytic and paralyzing effect.

The heating of all conductors in electric-heating appliances, or the quantity of metal deposited from a solution depends entirely upon the current in amperes. The volt is only the agent which keeps the amperes in action. In electric heat a certain number of amperes gives the proper temperature in a wire of a given size; the volts have only to do with forcing the amperes through various lengths of that wire. In a plating bath the electrodes of which require four volts to carry the current across, the number of amperes will be increased as the size of the article to be plated is increased.

The electric equation for the amperes is: $C = \frac{E}{R}$

In this C represents the current in amperes, E, the electromotive force in volts, and R the resistance in ohms.

A lamp the resistance of whose filament is fifty-five ohms is operated upon the one hundred and ten volt current and it is required to ascertain the current consumed. The equation would then read:

$$C = \frac{110}{55} = 2 \text{ amperes.}$$

I am making an ammeter and am ready to mark off the scale of readings. I have a battery which gives just thirty volts' pressure and three minature lamps of two ohms's resistance each with which to get the markings on my scale. The resistance of the connecting wires being negligible, what amperes would I get?

By placing the three lamps in series with the battery and meter our equation would read:

$$C = \frac{30}{2 + 2 + 2} = 5.$$

The point reached by the ammeter index would then be marked 5.

By taking out one of the lamps the equation would read:

$$C = \frac{30}{2 + 2} = 7\tfrac{1}{2}.$$

The index would swing to a point which we would then mark $7\frac{1}{2}$.

When the second lamp is taken which leaves one remaining the equation would read:

$$C = \frac{30}{2} = 15.$$

Our third position would then be marked 15. And now having the 0, 5, $7\frac{1}{2}$, and 15 ampere points definitely fixed, it is an easy matter to divide off the scale into finer readings.

THE OHM.

When water flows from a tank it meets with resistance of two kinds, due to the size of the pipe and the friction upon its walls, which determine the quantity that will flow under a given pressure. In like manner we may consider the flow of electricity. The water is first raised to a given height in the vessel which is analogous to the dynamo or battery creating potential. It then flows through the pipe at a rate and quantity proportionate to the height of the water in the tank, the size of the opening, and the length and condition of the pipe leading from the vessel. If there was no bottom in the vessel, the water would run out as fast as it runs in, and so it would be if a dynamo or battery were short-circuited through a very large conductor. But let the bottom be closed with the exception of a small opening and the water rises to a point determined by the size of the opening, the length of pipe leading from it and the condition of the inner surface of the pipe. That which opposes the flow of water is called friction while that which opposes the flow of electricity is called resistance and is measured in *ohms*.

There is no perfect conductor of electricity. All so-called conductors offer more or less resistance, and while some substances are frequently good conductors,

the metals are the best. Of these, silver stands at one extreme and bismuth at the other.

The table below gives the relative resistance of the various metals; it will also be observed that the conductivity is in a slight degree affected by the density. The condensation of a metal either by drawing or by rolling decreases the conductivity of a given cross-section. Silver, when annealed is the best metallic conductor, yet when it is hard drawn its conductive property becomes the same as copper.

Silver, annealed	1.
Copper, annealed	1.06
Silver, hard drawn	1.08
Copper, hard drawn	1.08
Gold, annealed	1.36
Gold, hard drawn	1.39
Aluminum, annealed	1.93
Zinc, pressed	3.74
Platinum, annealed	6.02
Iron, annealed	6.46
Gold-silver alloy, (2 oz. gold, 1 oz. silver)	7.22
Nickel, annealed	8.28
Tin, pressed	8.78
Lead, pressed	13.05
German silver	13.92
Platinum-silver, (1 oz. platinum, 2 oz. silver)	16.21
Antimony, pressed	23.60
Mercury	62.73
Bismuth, pressed	87.23

The resistance of all metallic conductors increases

with a rise of temperature, while, as a rule, the resistance of non-metallic conductors is reduced. Carbon and water, for instance, become better conductors upon being heated. The rise of resistance varies cosiderably in the different metals, that is, while one metal increases its resistance but little, another may double its resistance in rising but a hundred degrees.

The variation in resistance from rise of temperature is shown in the following table by Doctor Mathiessen:

Approximate percentage variation in resistance per degree C.

Platinum-silver alloy (1 oz. plat. 2 oz. silver)	.031
German silver	.044
Gold-silver alloy, (2 oz. gold, 1 oz. silver)	.065
Mercury	.072
Bismuth	.354
Gold	.365
Zinc	.365
Tin	.365
Silver	.377
Lead	.387
Copper	.388
Antimony	.389
Iron	.5

The variation in copper is quite large, and this is especially noticeable in the operation of a motor where it is allowed to become heated. It may be carrying a heavier load than it is designed for and instead of becoming stronger it becomes weaker and weaker, as it heats, until it is either burned out or is materially slackened.

It will be seen that the platinum-silver alloy varies the least and next to that is german silver. The expense of the former forbids its extensive use, so that german silver is used almost entirely for resistance coils. Where accurate measurements are desired, even if the platinum-silver alloy be used for resistance, the temperature must also be taken into account. On the other hand, the large variation in the resistance of iron under different temperatures precludes its use for rheostats, but this same property makes it valuable for other uses in electricity.

A third factor in the resistance of a conductor is the area of its cross-section. A large conductor offers less resistance or has greater carrying capacity than a small one. It does not matter what the shape of the conductor may be, whether it is flattened into a sheet, drawn into a tube, or is made into a solid rod, the conductive capacity is the same and is proportionate to the cross-section. It was once supposed that an electric current flowed upon the surface of the conductor, but this was disproven in two ways: First, the condensation of a metal was found to increase its resistance although the cross-section remained the same; and second, the rolling of a rod into a very thin sheet and thereby giving it a many times larger exposure of surface does not increase its carrying capacity, provided the same cross-section be retained. We can, therefore, sum up the whole matter of the conductivity of metals with regard to the cross-section of material in a very few words by saying that when an electric current flows in a metallic conductor the capacity of the same for conducting

the current lies in the cross-section of the material and not in any external form or appearance.

The following table gives the resistance of copper wire:

RESISTANCE OF COPPER WIRE.

American or B. and S. Wire Gauge.	*Ohms Per 1,000 ft.*	*Ohms Per Pound.*	*Feet Per Ohm.*	*Pounds Per Ohm.*
1	.126	.0005	7892.	1999.
2	.159	.0007	6258.	1257.
3	.200	.0012	4963.	790.6
4	.254	.0020	3936.	497.2
5	.320	.0031	3121.	312.7
6	.404	.0050	2475.	196.7
7	.509	.0080	1963.	123.7
8	.642	.0128	1557.	77.79
9	.810	.0204	1235.	48.92
10	1.021	.0325	979.1	20.77
11	1.288	.0516	776.4	19.35
12	1.624	.0821	615.7	12.17
13	2.048	.1307	488.3	7.653
14	2.582	.2078	387.2	4.813
15	3.256	.3304	307.1	3.027
16	4.106	.5253	243.5	1.904
17	5.178	.8353	193.1	1.197
18	6.529	1.325	153.2	.7529
19	8.233	2.112	121.5	.4735
20	10.38	3.358	96.33	.2978
21	13.09	5.339	76.39	.1873
22	16.51	8.490	60.58	.1178
23	20.82	13.50	48.04	.0740
24	26.25	21.47	38.10	.0465
25	33.10	34.13	30.21	.0293
26	41.74	54.27	23.96	.0184
27	52.63	86.29	19.00	.0115
28	66.36	137.2	15.07	.0728
29	83.68	218.2	11.95	.0045
30	105.5	346.9	9.477	.0028
31	133.1	551.6	7.515	.0018
32	167.8	877.1	5.960	.0011
33	211.6	1395.	4.727	.0007
34	266.8	2218.	3.748	.0004
35	336.4	3526.	2.973	.0003
36	424.2	5607.	2.357	.0002
37	534.9	8915.	1.869	.0001
38	674.5	11175.	1.183	.00007
39	850.6	22510.	1.176	.00004
40	1073.	35811.	.9324	.00002

A fourth factor in resistance is the length of the conductor. The resistance increases with the length. If

five feet of wire one-hundredth of an inch in diameter offers ten ohms' resistance, fifteen feet of the same wire will give three times that resistance, or thirty ohms. It is for this reason that it is not economical to supply constant-current electricity at long distances from the plant. In order to furnish it at the proper voltage, the cross-section of the conductor must be increased in proportion to its length. It requires a No. 15 copper wire to conduct current to fifty lamps fifty feet distant from the dynamo, but to conduct the current under the same voltage to fifty lamps one thousand feet distant, it requires a No. 2 copper wire which is about twenty times as large in cross-section as a No. 15 wire. From this it will be seen that the length of a conductor and its resistance is a very important factor in electricity.

Relative conductivity per cubic unit:

Metal.	*Electric.*	*Heat.*
Silver	100.0	100.0
Copper	94.1	74.0
Gold	73.0	54.0
Platinum	16.6	9.4
Iron	15.5	10.1
Tin	11.4	15.4
Lead	7.6	7.9
Bismuth	1.1	1.8

It is worthy of note that the relative conductivity of electricity and of heat in metals is approximately the same. This is shown in the above table by Weidmann and Franz.

Water, when absolutely pure, is classed as a non-conductor, or at least possesses a very high resistance, but when exposed to the air or acidulated, it becomes a conductor of marked capacity. The resistance of most liquids, however, is very great. Those substances which possess this property in a marked degree are used for insulators. Their resistance is so high that it is expressed in megohms, a million ohms.

Substance.	*Resistance in Megohms.*
Ice	284.
Water, at freezing point	150.
Mica	84.
Gutta Percha	450.
Vulcanite	28,000.
Paraffine	34,000.
Glass	3,000,000.
Air.	Infinite.

The electrical formula for resistance is $R = \frac{E}{A}$

A lamp of sixteen candle-power consumes half an ampere at one hundred and ten volts. Required, the resistance of the filament.

$$R = \frac{110}{.5} = 220 \text{ ohms.}$$

A rheostat is used on the one hundred and ten volt current, and gives two amperes on the first contact, three amperes on the second, four on the third and five on the fourth. What is the resistance on each contact?

The first would be $\frac{110}{2} = 55$ ohms.

The second would be $\frac{110}{3} = 36.6$ ohms.

The third would be $\frac{110}{4} = 27.5$ ohms.

The fourth would be $\frac{110}{5} = 22$ ohms.

THE WATT.

Electric energy, whether it is manifested in the revolving armature of a motor, the heating of an oven, or in the deposition of a metal from its solution, can be readily computed in horse-power. We have seen that the volt in electricity means the same as pressure in hydraulics, and that the ampere is the same as the cross-section of a flowing stream of water. All electric work depends upon the two factors, pressure and current, in whatever proportions they may be. A current may be under a thousand volts' pressure, or it may be under but a few; it may be a current of many amperes or of but the fraction of one. The volts multiplied by the amperes give a result which accurately represents the energy which is active in any current. The term for the product of the pressure in volts, into the current in amperes, is the *watt*. This is sometimes called the *volt-ampere*, and is the unit for electric power. It has been found that 746 watts are equal to one horse-power. It does not matter how the watts are made up, whether more of volts than of amperes, so long as their product equals 746, there is an energy of one horse-power.

The watt is beautifully illustrated in the study of the electro-magnet. Magnetism is developed in the core of the magnet by the circulation of an electric current around it. We will suppose that we have a wire which will carry two amperes and this wire makes five turns around the core as shown in Fig. 7. Each turn of the wire carries two amperes, and, since there are five turns of the wire around the core, these two amperes go around five times, so that there may be said to be ten amperes circulating at onee. Now suppose that instead of the five separate turns of wire the insulation is removed from the wire so that the five turns touch laterally so as to form a solid band encircling the eore. They would then act as one turn of wire one-fifth as long and five times as large on cross-section and would then earry ten amperes but only once around which would produce the same magnetic strength as five turns of two amperes each. We may suppose an electro-magnet has five hundred turns of wire around it and one hundred and ten volts are required to force three amperes through it; there would then be an expenditure of three hundred and thirty watts, a little less than half a horse-power. Suppose now that we only have two hundred and fifty turns of wire on the magnet and our voltage is but fifty-five, the amperes would

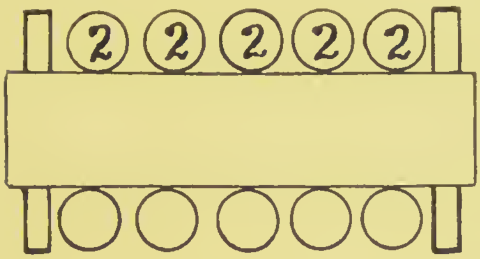

FIG. 7.—DIAGRAMMATIC ILLUSTRATION OF THE WATT.

still be three but the magnetic field is but half the former strength.

The watt is a unit relatively so small that it is most appropriately used in speaking of the consumption of very small quantities of current. In dynamo electricity the term kilowatt, (a thousand watts,) is generally used. It is usual to speak of the dynamo as one of so many kilowatts, but of the motor as one of so many horse-power.

There are three expressions for the watt or volt-ampere:

(1) $CE =$ The Watts.

(2) $\frac{E^2}{R} =$ The Watts.

(3) $C^2R =$ The Watts.

In the first the watts are equal to the product of the current in amperes multiplied by the pressure in volts. In the second the electric power is inversely as the resistance when the voltage is constant, and is proportional to the square of the electromotive force when the resistance is constant. In the third the power varies as the resistance when the current is constant, or as the square of the current when the resistance is constant.

A sixteen candle-power lamp consumes five-tenths of an ampere at one hundred and ten volts: how many watts per candle power?

$$W = 110 \times .5 = 55.$$
$$16 \text{ C. P.} = 55.$$
$$1 \text{ C. P.} = 3.4 \text{ Watts.}$$

An electromotive force of fifty-two volts is operating

through a resistance of one hundred ohms; how many watts are operative?

$$W = \frac{52^2}{100}$$
$$W = 27.$$

A rheostat has a resistance of thirteen ohms and nine amperes flow through it. How many watts are dissipated?

$$W = 9^2 \times 13.$$
$$W = 1053.$$

A dynamo has an output of nine amperes at two thousand volts. What would that be in watts and horsepower?

$$W = 9 \times 2000 = 18000 \text{ Watts.}$$
$$\frac{18000}{746} = 24 \text{ horse-power.}$$

THE COULOMB.

When we measure the rate of flow of liquids we estimate the amount in cubic inches or cubic feet per second; or, sometimes, the gallons per minute. So in the measurement of the rate of flow of electricity, we estimate it in so many units of quantity of electricity per second. When a current of a given strength flows it is called a current of so many amperes. This term has no reference to the length of time the current flows but simply to the volume of the current. Although electricity is not usually so considered, we might with pro-

priety call the amperes the cross-section of the current. It is not until the element of time is considered in connection with the current in amperes that we can estimate the quantity consumed. When a current of so many amperes flows for a given time, a quantity of electricity has been active which may be measured with the utmost accuracy by the work it has done.

The term for electrical quantity is called the *coulomb,* from Charles A. Coulomb, a French electrician. It means such a quantity of electricity as shall pass in one second in a circuit of one volt pressure and one ohm resistance, or one ampere flowing for one second. The term "coulomb" also applies to static electricity and means the quantity of electricity contained in a condenser of one farad capacity under a pressure of one volt.

While we cannot see a coulomb of electricity we can accurately measure it by its effects. At the ordinary temperature and pressure, eighty-seven coulombs passing through water will decompose the water and liberate one cubic inch of oxygen and hydrogen in the proportions in which they are combined in the molecule, or 25,358 coulombs will deposit one ounce of silver from its solution. A sixteen candle-power one hundred and ten volt lamp requires half an ampere to properly light it. It would then consume half a coulomb in one second, or eighteen thousand coulombs in ten hours. A current of this strength would deposit an ounce of silver in fourteen hours.

The term "coulomb" is one liable to be confused with the term "ampere." They both have reference to the

flow of current. The ampere, however, refers to the strength of current flowing while the coulomb refers in particular to the length of time that a current of a given volume flows. The ampere may be said to be the cross-section of the current as it flows, and the coulomb to be the quantity that has passed a given point in a certain period of time. When compared with the flow of water in a pipe, the ampere represents the rate at which water is flowing, and the coulomb represents the quantity that has passed in a given length of time.

The foregoing explanation of the common terms in electricity will suffice for our purpose in an elementary study of this kind. The other technical terms will be explained as they are used.

CHAPTER III.

Magnetism.

It is a remarkable fact that the mysterious force, electricity, should be so intimately connected with one equally as mysterious, magnetism. The discovery of magnetism preceded the discovery of electricity some centuries, but the only practical use made of it, up to the time of the discovery of this new property of the electric current by Oersted in 1820, was for the mariner's compass. The common phenomena of magnetism were regarded more as a curiosity than as of any practical value.

Iron ore, known as magnetite, when pure, sometimes possesses the peculiar property of attracting pieces of iron to it. This substance is sometimes known as *lodestone,* and is called a *natural magnet.* The name "magnetism" was derived from Magnesia where it is supposed the first lodestone was found. It is supposed that the beds of this ore concentrate the lines of the earth's magnetic field upon themselves and the ore thus becomes magnetic. If a lodestone is brought in contact with a bar of iron it will induce a magnetic property in the iron bar. This is then called an *artificial magnet.* If the bar be of hardened steel the magnetic property which it received from the lodestone will be retained for a considerable length of time and it is called a *permanent magnet;* whereas, if the bar be of soft iron

it will lose its magnetic property upon removing the lodestone. For this reason the soft iron is called a *temporary magnet.*

MAGNETIC PHENOMENA.

If a bar of hardened steel which has been magnetized be rolled in iron filings, it will be found that the filings will be attracted to the bar and will collect in large quantities about the ends of it, as shown in Fig. 8.

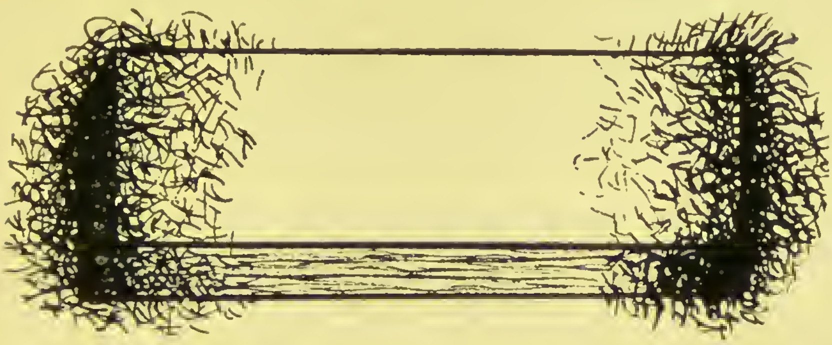

FIG. 8.

The heaping up of the filings about the ends indicates that the attraction is strongest at these points. If a piece of iron be suspended on a delicate weighing machine and a bar magnet be passed under it at the same perpendicular distance, but at different points horizontally, it will be noticed that the attractive power is greatest at the ends of the magnet and that it gradually diminishes toward the center. The difference in the magnetic strength in different parts of the bar with points of greatest intensity at the extremities was named by Doctor Gilbert, the *poles* of the magnet.

Another peculiarity observed in the magnetized bar is that if a piece of soft unmagnetized iron be presented

at each of its poles, there will be the same magnetic pull at either end. If, instead of the soft iron, one end of a bar of magnetized steel be presented to one pole of the magnet, there will be a much stronger attraction, but if the other end of the bar be presented it will be repelled. This shows that while both ends of the bar magnet possess the same attractive pull on a piece of soft unmagnetized iron, it depends upon which pole of the magnetized bar is presented whether it will be attracted or repelled, indicating that the magnetism at either end of the magnet, while of the same strength is not of the same character. Upon experiment it was found that the two ends of the bar magnet are of opposite polarity, and they were accordingly designated positive (+) and negative (—) poles.

It was also found that while the two ends of a magnet were of opposite polarity, the positive of one magnet would repel the positive of the other, and that attraction only took place between ends of opposite polarity. Based upon these phenomena, the following laws of magnetic attraction and repulsion have been established:

1. Like magnetic poles repel each other.
2. Unlike magnetic poles attract each other.

The attractive force of magnetism does not vary in proportion to the distance, because it is found that when metals are in actual contact its power is not only greatest, but upon breaking the contact the attraction decreases very rapidly in a very short distance.

If a steel bar which has been magnetized be balanced and delicately suspended, it will assume a direction pointing north and south, and that end pointing north

will be found to be the positive pole, and that pointing south will be the negative pole. For this reason the positive is sometimes called the *north pole,* and the negative, the *south pole.* The cause of the magnetic needle assuming a northerly and southerly direction is due to the fact that the earth acts as a huge magnet with its negative pole at the north and its positive pole at the south. There was at one time some discussion as to whether it would not be more scientific to call that pole which pointed to the north, the south pole of the magnet, since the negative or south magnetic pole of the earth is at its north pole, but the old form is still retained.

If a soft iron nail be brought in contact with another nail there is apparently no magnetic action between them and they remain quiet. If, however, a magnet be placed upon the first nail, the second nail will be drawn to the first much as if the first nail was of steel and was a permanent magnet; and if a third nail be placed near the second this will cling to the second as the second did to the first. Upon removing the magnet from the first nail they all fall apart.

This phenomenon shows not only that soft iron possesses a magnetic property, or power, when in the field of a permanent magnet, but that during this time it has a magnetic property of its own sufficient to attract other pieces of iron. The magnetism produced in the nails is called *induced magnetism* because it is induced in them for the time being by the permanent magnet.

If a magnetic needle be brought near the nail while it is magnetized by the permanent magnet, it will be found that the induced magnetism of the nail possesses

a difference of polarity like that of the permanent magnet, and that the end of the nail in contact with the magnet will be of opposite polarity to that pole of the magnet. It will be further seen that the induced magnetism of the second nail at the contacting point with the first nail is also of opposite polarity and so on throughout the series.

If a glass tube be nearly filled with steel filings and it be brought in contact with a strong magnet, it will be found that the whole tube will act as a magnet and show a difference of polarity at its ends. If now the filings be shaken up, this difference of polarity will be lost. An examination, however, of one of these steel particles will show that it has not lost its magnetism, but exhibits a difference of polarity at its ends. The result of shaking them up has been to place them in such positions that their polarities have neutralized each other. If they could be placed in their original positions the polarity of the whole tube would be restored. This indicates that magnetism has been induced in each particle and that each particle possesses a difference of polarity at its extremities.

If a knitting needle be magnetized, we will find that it has two poles, one at either end and in its center, a neutral point. If we break it at the neutral point, it will be found that we will not have one piece of one polarity and the other piece of the opposite polarity, but that each piece has ends of opposite polarity like the original needle. Break one of these pieces at its neutral point again, and we still have the same difference of polarity shown at the extremities. It does

not matter into how small pieces our needle is broken, each piece will exhibit a difference of polarity like the original whole needle. This indicates that if the division could be kept up till the molecules are reached, each molecule would be found to be a magnet with a difference of polarity and that *magnetism is a phenomenon residing in the molecules of the substance.*

If, again, a steel magnet be heated, it will be found that the magnetism has been lost. The reason for this is that, if magnetism resides in the molecules of the substance, as supposed above, while the steel is heated the molecules are in irregular agitation and, as in the illustration of the steel filings, do not resume their original positions on cooling. Consequently the magnetism is neutralized by the pairing of the molecules. When we strike a permanent magnet a hard blow its polarity is lost because of the disturbance and new arrangement of its molecules.

THEORY OF MAGNETISM.

One of the earlier theories of magnetism held that it was due to the presence of two different fluids, one boreal or north, and the other austral, or south. In most substances these fluids are in a state of equilibrium and cannot be separated, but in some bodies like iron and nickel they are capable of separation and the phenomenon of magnetism is due to this separated and unbalanced condition.

Soon after Oersted announced the magnetic property of a conductor through which electricity was flowing,

Ampère proposed a theory for magnetism based on that phenomenon. This theory while not generally accepted to-day was a step in advance and opened the way for further investigations. The theory of Ampère was as follows:

1. That the ultimate particles of all magnetizable bodies form closed circuits in which currents of electricity are constantly flowing.

2. That in an unmagnetized body these currents are still present, but that the currents flow in opposite directions in adjoining circuits and therefore neutralize one another.

3. That the act of magnetization consists in such movement of polarization of the particles as will cause the currents in all to flow in one and the same direction, magnetic saturation being reached when they are all so caused to flow in one and the same direction.

4. That the coercive force is due to the resistance which these circuits or the particles through which they flow, offer to a change in their direction.

The above theory of Ampère is open to the objection that it is contrary to the laws of nature in that we know that electricity cannot be continually flowing in a substance without an expenditure of energy.

To meet the objections of Ampère's theory Professor Hughes proposed one by assuming:

1. That the ultimate particles of matter naturally possess opposite polarities; namely, +, or north, and —, or south.

2. That when these ultimate particles are arranged in closed circuits or chains, with their opposite poles

together, they completely neutralize one another so far as any external effect is concerned.

3. That the act of magnetization consists in a rotation of these ultimate particles so as to cause all the positive poles to point in one and the same direction, and all the negative poles to point in the opposite direction.

The theory of Hughes, while it is not entirely satisfactory, is supported by the following facts:

1. A bar of steel or iron increases in length on being magnetized. This is due to the ultimate particles arranging themselves with their opposite poles together.

2. A glass tube filled with water containing very fine magnetic oxide of iron is nearly opaque. If this be magnetized it will allow light to pass through it.

3. A magnet may be divided into any number of pieces, and each piece will still have a north and south pole.

4. It was shown by Von Betz that iron which is electrolytically deposited upon the poles of a magnet increases the strength of the magnet, because the ultimate particles have been more distinctly arranged by the electrolytic process than they can be by the ordinary process of magnetization upon the particles in the steel bar.

The most generally accepted theory of magnetism is that proposed by Professor Ewing, and this is a modification again, of Hughes's theory. He agrees with Hughes in assuming that the ultimate particles of matter are naturally magnetic and possess polarity, but differs from him in regard to the force which resists the

movement of the molecules during their polarization. Professor Ewing maintains that no other force than ordinary attraction and repulsion exists between the molecules, and that they are free to rotate about their eenters and maintain the same distance from one another during this rotation. He demonstrated this prineiple with a number of small needles under the influenee of a magnet.

The theory of Ewing is strengthened by what has been observed in regard to magnets. A steel rod is more quiekly and thoroughly magnetized if it is subjected to light jars or vibrations during the magnetizing proeess. A magnet loses its polarity if its temperature be raised high enough to set the moleeules in motion.

This theory holds that magnetism resides in the ultimate partieles, that the molecules themselves are as small magnets which inherently possess a north and south polarity. These partieles in their original positions, like the disturbed filings in the glass tube, have their polarities neutralized by their promiseuous arrangement. Upon being brought under the influenee of a strong magnet these particles behave like the small compass needle and arrange themselves according to the laws of magnetic polarity. During magnetization the ultimate partieles rotate until there is a more or less perfeet alignment with the same poles pointing in the same direction. The bar becomes magnetized to *saturation* when all the particles have thus aligned themselves.

The difference in the facility with which iron and

steel are made magnetic, and the difference in their power of retaining the magnetic property, is due to the physical property of each and not to any chemical condition. A piece of tempered steel is hard because its particles possess a compactness and rigidity which is not easily changed, whereas, a piece of iron is soft because its particles are more loosely arranged and are more mobile. Now since magnetism resides in the molecules, and since the process of magnetization is one in which there is a rotation and alignment of these molecules, it is evident that a metal whose molecules are loosely arranged will be easily magnetized, whereas a metal whose molecules are not so free to move will be difficult to magnetize. It is evident also that the particles of a metal which are so loosely arranged as to be easily rotated by an external magnetic force will quickly regain their original positions on removal of the magnetic force; and on the contrary the particles of a metal which are difficult to rotate will retain their magnetic positions for a longer time.

In this way we account for the facility with which soft iron becomes magnetic, and also for the difficulty experienced in magnetizing hardened steel. In like manner we also account for the difference in the retentive property of soft iron and steel. The molecules of soft iron being free to move, quickly regain their original position, whereas, those of hardened steel, having been once aligned, retain their positions for a long time. It is for this reason that a bar of steel will be difficult to magnetize, but will retain its magnetic property in proportion to its hardness.

The ease and facility with which soft iron can be magnetized and the rapidity with which it loses its magnetism is the underlying principle of all electromagnetic mechanisms. The dynamo for generating electric currents, the motor for transforming their energy into work, the electric bell, the telephone, the telegraph, and many other electrical appliances have as their fundamental mechanism, or central organ, a magnet.

Two theories have been proposed to account for the magnetism of the ultimate particles of iron. There is a very subtle and highly elastic medium which exists everywhere in space and even pervades all substance, filling the intermolecular spaces. This medium, which is called the *ether,* is a frictionless fluid and is the medium which transmits light, heat, electricity, and magnetism When it is once set in motion it requires no additional energy to keep it moving. One of the theories of magnetism presumes that a magnetized molecule produces a whirl in the ether surrounding it and that these whirlings, or vortices, are the cause of the phenomena. The other theory is somewhat similar to this, but differs in that these whirlings are so much in one direction that they are called streamings. It is believed that each molecule which exhibits the magnetic phenomenon causes a streaming motion of the ether through it. These molecules may be moved and rotated far enough that the streamings are all in one direction. In the unmagnetized state of a bar of iron these molecular magnets possess no definite alignment so that their streamings neutralize one another, but upon the application of a strong magnet the mole-

cules align themselves so that their streamings become co-directed. There is then a strong ether streaming passing through the bar and we have perceptible magnetism.

It is presumed that the magnetic streamings enter at the south pole of the magnet and issue at the north pole as shown in Fig. 9.

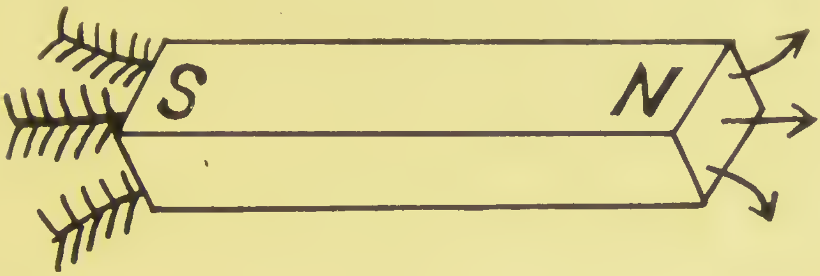

Fig. 9.

These streamings are sometimes called *lines of magnetic force, magnetic flux,* or *tubes of magnetic force.* It is supposed that they are set in motion by the molecular mechanism of the magnet, and flow through it from the south to the north pole, then complete the circuit by returning to the south pole in the opposite direction through the external region. The phenomena of attraction and repulsion are accounted for in this way: If we suppose that the streamings leave the magnet at the north pole, then if the north poles of two magnets be brought together, the streamings from one magnet will be against those of the other and we will have a repulsion of the magnets. If, however, the south pole of the second magnet be placed at the north pole of the first, then the streaming from both magnets will be in the same direction and will flow from the first into the second exhibiting the stronger magnetic attraction. A

compass needle which is free to rotate, when approached by one of the poles of a bar magnet will rotate till its magnetic streamings are co-directed with those of the magnet and will come to rest with an opposite pole contacting that of the magnet.

ELECTROMAGNETISM.

In 1820 Oersted, of Copenhagen, made known the important discovery that a conductor carrying a current of electricity possesses properties like those of a magnet. The similarity between the nature of electricity and that of magnetism in some of their phenomena, had aroused the suspicion that there was a relation between the two, but up to that time there seemed to be no connecting

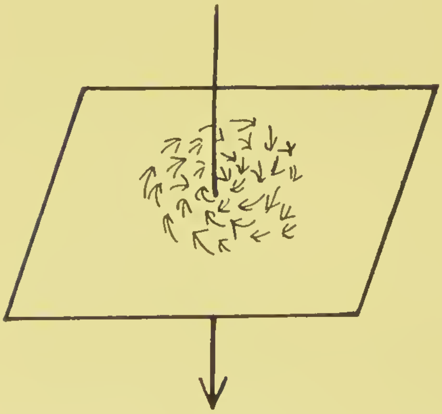

FIG. 10.

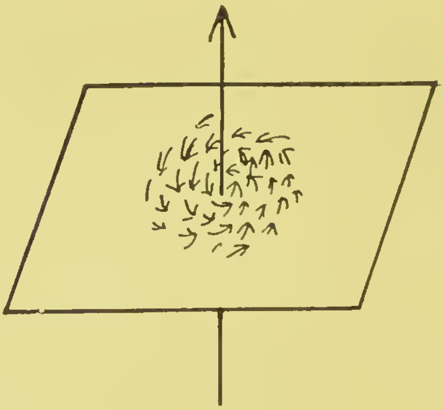

FIG. 11.

link. Oersted demonstrated this relation by closing the circuit of a voltaic battery and bringing a compass needle near the conductor. And at this day any one can make the experiment by bringing a penknife near an incandescent lamp. The magnetism accompanying the flow of current through the filament will cause it to be

attracted or repelled from the knife according to its polarity. The magnetic field produced by a flow of current through a conductor can be shown by passing the conductor perpendicularly through a cardboard and sprinkling iron filings on the card. If the card be gently tapped the filings will arrange themselves in concentric circles around the conductor as shown in Fig. 10.

The filings have not only been drawn into this grouping but at the same time have become magnetic and exhibit a difference of polarity. The polarity of the filings depends upon the direction in which the current flows through the conductor. If the current flows downward then the lines of magnetic force take a direction like the hands of a clock. This can also be illustrated by the motion of a right-handed corkscrew. The forward movement of the screw represents the flow of the electric current and the rotary motion which it takes represents the lines of magnetic force. If the current flows up through the wire in the cardboard then the direction of the lines of magnetic force is reversed and we have the condition shown in Fig. 11.

When a number of complete turns are made from a single piece of wire so as to form a coil it is then called a *helix* or *solenoid,* and possesses all the properties of a magnet. Its behavior is in every way similar to a bar magnet. It possesses the property of direction like the magnetic needle and the property of attraction and repulsion. If a solenoid be so arranged that it is free to rotate at the same time that it carries the current, it will assume a northerly and southerly direction like the needle of a compass. Or if it be approached by one

pole of a permanent magnet, it will assume a position according to the laws of magnetic attraction and repulsion.

A single turn of wire will produce a certain amount of magnetic flux, and it is found that if another turn of the same wire be added the flux will be doubled although the same amount of energy may be expended. The streamings of each turn are added to the first and there is no limit to the extent to which the loops or coils may be added and to the intensity of the magnetic flux.

The magnetic flux of a circuit can be expressed in a formula similar to Ohm's law of electric-current flow. The unit of magnetic flux is the *weber,* the unit of magnetomotive force is the *gilbert,* and the unit of magnetic reluctance is the *oersted.* The term "magnetic flux" corresponds to the term "ampere," magnetomotive force to electromotive force, and magnetic reluctance to resistance. The expression for the above is,

$$\text{Webers} = \frac{\text{Gilberts}}{\text{Oersteds}}$$

which corresponds to the electrical equation

$$\text{Amperes} = \frac{\text{Volts}}{\text{Resistance}}$$

THE ELECTROMAGNET.

The electromagnet is one of the most important electric inventions. Without it we could not generate current on a commercial basis, and without it the use of electricity would be limited almost entirely to electrolytic processes. The electric light would be a curiosity, and we could have no motive power of any kind. The

telegraph, telephone, electric bell, and many other appliances which have for their central organ an electromagnet, would be unknown.

If a bar of soft iron be introduced into the coils of a helix, its molecules are aligned by the influence of the electric current the same as if it had been brought in contact with a permanent magnet, and the iron which is then made magnetic by the electric current is known as an electromagnet. The magnetism of the helix alone is considerable, but when to this is added the natural magnetism of the aligned molecules of the iron, we have a doubling of the streamings; and, since there is no limit to the number of turns that may be made in the helix and their more perfect aligning effect upon the iron molecules, the strength of the electromagnet may be increased almost indefinitely. This is one of the features of this appliance. The simple closing of a circuit with a switch may put into operation many horsepowers of energy.

The electromagnet can not only be made of any desired strength, but the rapidity with which it becomes magnetized and demagnetized by the closing and opening of the electric circuit makes it one of the most important and widely used principles in the production and application of modern electricity. The dynamo which generates and the motor which uses the current each depends upon the facility with which its magnets receive and lose their magnetism. In the iron core of the transformer we have not only a break in the magnetism but an actual reversal of the poles and this occurring hundreds of times in a second. It is difficult

to conceive of all that takes place in so short a period of time. The armature of the telegraph and the receiver of the telephone each operate by the varying magnetism of the electromagnet. It may require an appreciable length of time for a large iron core two feet in diameter to lose its magnetism, but an iron wire of 14 gauge will both acquire and lose it in approximately a hundred-thousandth of a second.

The most common form of the electromagnet is the one in which there are two iron cores and a connecting piece called the *yoke*. Soft iron is used for these parts because it has the property of quickly losing its magnetism on opening the circuit. The cores are fitted with end pieces to keep the wires in form, and the intervening space is wound with insulated copper wire. These two bobbins are then placed side by side and the yoke fitted on the upper ends of the cores, making as much contact as possible, so that all three pieces will be as one continuous piece of iron. The wire from one bobbin is then connected with the wire of the other bobbin and the magnet is complete. In connecting the wires of the two bobbins, it should be so done that the current passes around U-shaped iron cores in a direction the same as if the cores and yoke were straightened out into one piece and the wire were wound on one bobbin and then the other without change of direction. The U-shaped magnet is simply a straight magnet with opposite poles at its extremities bent in that form for the purpose of bringing the poles nearer together.

The amount of magnetic flux in an electromagnet is approximately as the number of turns of wire on the

spool, the electric current remaining the same. If we have a spool with five hundred turns on it and five hundred more be added, the magnetic flux will be almost doubled. If a wire carries one ampere of current it will be known as an *ampere turn*; but if it carries but half an ampere it will require two turns to make one ampere turn.

The amount of magnetic flux in a coil without the core is directly proportionate to the strength of the magnetizing current. If a current of one ampere is flowing through a coil, the magnetic flux will be doubled if an additional ampere be caused to flow.

The laws of electricity, like a rule in mathematics, are always the same, and the electrical engineer in the course of time has established data and rules of such precision that a motor or dynamo can be designed for any capacity or any service with absolute assurance that it will be the most efficient.

CHAPTER IV.

Sources of Electricity.

Electricity is everywhere and is a phenomenon of every-day life, but it is so readily dissipated that it is not always apparent. It may be produced by the simple contact of dissimilar substances, by the friction of one substance against another, or by a difference of temperature. It is present in the physical and chemical processes of animal and plant life. Although the various conditions under which it manifests itself would lead one to believe that there are different kinds of electricity, yet there is but one electricity, and the different terms voltaic-electricity, thermo-electricity, etc., are simply names to designate the source of the current.

The sources of electricity may be grouped under seven heads as follows:

1. *Thermo-electricity*, or that produced by a difference of temperature at the junction of two dissimilar metals.

2. *Voltaic-electricity*, or that produced by the unequal action of an electrolyte upon two dissimilar substances.

3. *Dynamo-electricity*, or that produced by the motion of a conductor past a magnet.

4. *Frictional electricity*, or that produced by the friction of one substance against another.

5. *Pyro-electricity*, or that produced by differences of temperature in certain crystalline solids.

6. *Photo-electricity,* or that produced by the action of light.

7. *Vital electricity,* or that produced under the influence of and during the operations of life.

Only the first four sources of electricity are of sufficient capacity to have any commercial value, and to be discussed in this work.

THE THERMOPILE.

When two dissimilar metals are heated at their junction an electric current flows which may be easily measured. This is called a thermopile, and while it is not an economical method of producing current, it is nevertheless an interesting phenomenon and illustrates the relation between heat and electricity. There is a reciprocal action between electricity and other modes of motion. Electricity produces magnetism and magnetism produces electricity. Electricity produces light and light produces electricity. And in like manner electricity produces heat and heat produces electricity.

If a bar of bismuth and one of antimony be joined together, a current of electricity will be generated if their junction be heated. A number of such couplets joined, forms a thermopile whose strength increases with each additional couplet. The current flows across each heated junction from bismuth to antimony, and across each cooled junction from antimony to bismuth. At each junction it receives a fresh impulse according to the difference of temperature between the two ends of the couplet.

Here we have an illustration of electricity generated

by heat. There is a difference of heat potential which produces the difference of electrical potential, and, upon completing the circuit, we have a flow of electricity. The specific capacity of bismuth for heat is three-hundredths while that of antimony is five-hundredths. When heat from the same source is applied at the junction of the two metals there is a rise in the temperature of each inversely as their specific capacity, the bismuth becoming much hotter than the antimony. This difference of heat potential creates a difference of electric potential and the current flows from the bismuth to the antimony.

In the use of these two metals for the thermopile, there is another condition favoring a greater difference of electrical potential which is due to their molecular structure. A difference of crystallization affects the electric potential. These metals crystallize in different forms and of such a marked difference as to increase the electric current. For these two reasons the antimony-bismuth couplet is the one most used for generating current by heat.

Fig. 12—Thermopile Couplet.

As stated at the outset, there is a reciprocal action between heat and electricity. If, instead of heating and cooling alternate junctions of the couplet, a current of

electricity be passed through the thermopile, the junctions will become heated or cooled according to the direction of the current. One passing from antimony to bismuth heats the junction, while, if in the opposite direction the junction will be cooled.

It is an easy matter to convert electrical energy into heat energy. As a matter of fact this transformation

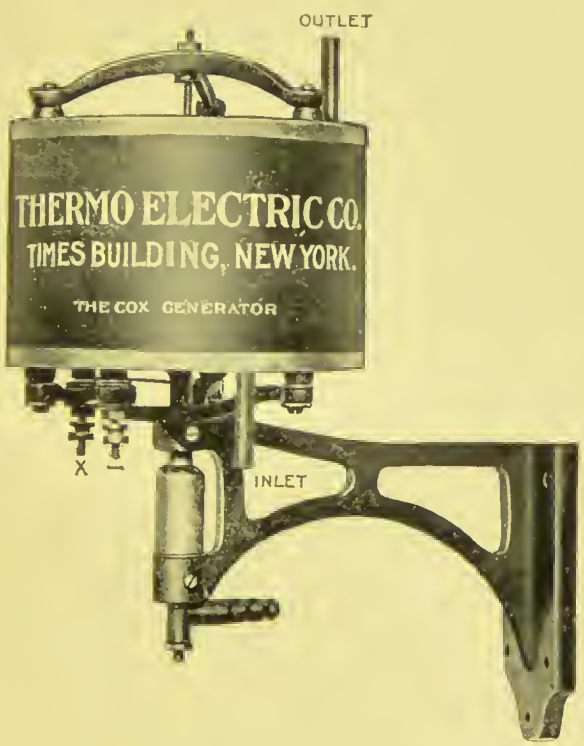

FIG. 14—THERMO ELECTRIC CO.'S THERMOPILE.

can be accomplished without any appreciable loss. This, however, is not the case in the reverse order. Heat cannot be converted into electricity except with a loss of about sixty per cent. even with the best appliances of to-day.

The quantity of current derived from the thermopile

is not very large, and on that account this method of generating current has not been of much commercial value till recently when the Thermo Electric Company placed an appliance upon the market which promises to become a practical and efficient instrument. This is shown in Fig. 14. The couplets are arranged in a circle around a central heating space. The heat is supplied by a Bunsen burner which heats the inner junction and in order to obtain the greatest difference of temperature the outer junctions are kept cool by a water jacket which surrounds them.

The output of one of these appliances with water back is about twenty watts, and the couplets can be connected up so as to give ten volts and two amperes or *vice versa*. This is sufficient for many dental instruments such as the electric plugger, fan, engine, and cautery or mouth lamp.

THE BATTERY.

In 1767, Sulzer, of Berlin, discovered that a peculiar taste was produced by placing two coins of different metals upon the tongue in such a manner that their edges touched. The significance of this discovery was not comprehended till some twenty years later, when in 1786 Luigi Galvani announced his experiment with frog's legs. It was supposed that he had discovered the cause of vitality; in fact, Galvani claimed that he had discovered the vital fluid and principle of life. Alexander Volta, however, upon investigating the phenomena which were produced by the action of dissimilar metals when brought in contact with the nerves and muscles

of the frog's leg, ascribed the movement to a light electric current which was produced by the contact of the metals, and flowed through the nerves and muscles. These metals when inserted in the frog's leg would undergo a slight oxidation, and the electricity developed from the chemical action coursing through the leg produced the contractions. The frog's legs took the place of the exciting liquid in the galvanic cell.

Volta, in following up his experiments, in order to intensify the action of the dissimilar metals constructed what was named the *artificial electric organ* but which is now known as the *voltaic pile*. This consisted of discs of copper and zinc laid upon one another, forming a couplet upon which was laid a cloth moistened with salt water. Some fifty of these were piled one upon the other, observing the order of copper, zinc, cloth, and the whole fastened together and forming the voltaic pile.

While the combination of parts in which electricity is produced by chemical action is called a galvanic cell, it should properly be called a *voltaic cell*, and a number of such cells acting together is called a *battery*.

The voltaic cell consists of two parts:

1. A voltaic pair or couple.

2. A liquid called the electrolyte in which the voltaic pair is immersed.

The couplet is generally made up of two solids, which are dissimilar metals. Or, one may be a metal and the other carbon. In some cells, however, the couple is made up of solids and liquids, of liquids and gases, or even of different liquids or different gases. In the

Grove gas battery, the couple is composed of oxygen and hydrogen. If metals or carbon are used, they are usually in the form of plates so as to present considerable surface to be acted upon.

The electrolyte is a fluid, generally but not always of acid reaction. The function of the fluid is to act upon one of the metals of the couple, and it must at the same time be capable of being decomposed and of conducting the current. Acid fluids are more active in their chemical reactions than alkaline ones, and it is for this reason that the solution is generally of acid reaction. For some uses of the cell, however, the best results are obtained by having the fluid of an alkaline reaction.

During the action of a cell, one of the plates is acted upon by the electrolyte with which it enters into chem-

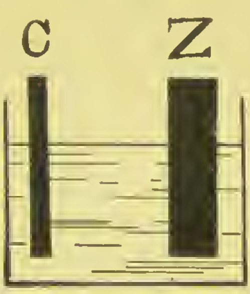

Fig. 14.

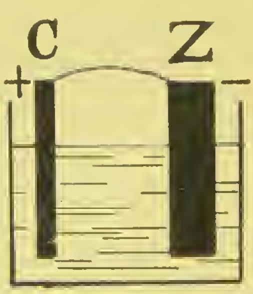

Fig. 15.

ical combination, and while the other plate may not be affected by the electrolyte, however, it has its functions to perform. We may say that nearly all of the chemical process centers at the plate which is being acted upon by the electrolyte, and that the other plate acts as a means of taking care of some of the products formed by the action upon the first plate.

A familiar type of voltaic cell is that which has cop-

per and zinc elements with dilute sulphuric acid for the electrolyte. If the zinc is placed in the acid solution first, it will be slightly acted upon, and bubbles of hydrogen gas will collect upon it; if then the copper plate be immersed but not allowed to touch the zinc, as in Fig. 14, there will be no change further than the slight disturbance of the liquid. If now the copper and zinc be connected by a wire as shown in Fig. 15, an electrolytic action takes place in the cell. The solution is decomposed, the zinc plate is attacked by the acid, and bubbles of hydrogen form on the copper plate. The action upon the zinc plate causes the formation of zinc sulphate which is quickly dissolved by the solution.

The foregoing statement of the chemical reactions is according to the generally accepted theory of Grotthus, and is expressed in the following equation:

$$Zn + H_2SO_4 = ZnSO_4 + 2H.$$

The electro-positive elements form a procession moving in one direction and the electro-negative, one moving in the opposite direction. All metals, and hydrogen which is supposed also to be a metal, move in the direction of the positive of the current. The sulphuric acid is broken up; the sulphur and oxygen in the form of Sulphion, SO_4, unite with the zinc forming zinc sulphate, and the hydrogen, while it is set free at the copper plate, has no affinity for the copper and consequently forms in bubbles upon its surface as free hydrogen.

In the chemical reactions there has been a transfer of energy. The zinc sulphate has a lower molecular energy than the combinations from which it was formed,

and the energy which was liberated during the reaction appears now in the form of heat and electricity.

According to one of the theories, during the splitting up of the molecules according to their affinities, those moving towards the copper plate carry a positive charge of electricity and those which move toward the zinc plate carry a negative charge. In this way, if the two plates are connected externally, the charges of electricity received by one of the plates are conducted to the other, and we then have our electric current established and flowing from the copper to the zinc plate outside of the solution and from the zinc to the copper within the solution. At the same time the copper and zinc plates have a + and — pole, much as if they were magnets, with the neutral point at the surface of the solution. The exposed end of the copper plate is positive, and the current flows from it toward the zinc through the connecting wire. Within the solution, however, the condition is reversed and the immersed end of the zinc plate is positive, and the current flows from that to the immersed end of the copper, the latter being negative.

In practice the copper plate is referred to as the negative because the current from the solution enters it, and the zinc plate as the positive because the current leaves it to enter the liquid. Moreover, it is the positive plate which is acted upon, and the negative plate which is not. The wire which conducts the currents from the copper plate is called the positive electrode, and the wire from the zinc the negative electrode because they are of that polarity.

In any voltaic cell the direction of the current through the liquid is the opposite of that without. Within the solution the current flows from the plate most acted upon to the other, and outside the liquid, from the plate least acted upon to the one most acted upon as shown in Fig. 16.

The zinc which is used for batteries should be chemically pure. If it contains other mteals, voltaic couples will be formed in the zinc itself, and in that way the efficiency of the cell will be diminished. The impuri-

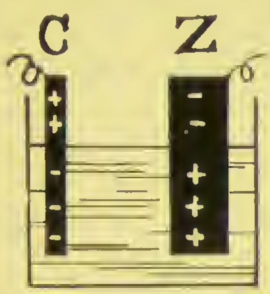

FIG. 16—VOLTAIC COUPLE.

ties produce currents which flow round in short circuits through the liquid and back to the zinc again. Zinc without impurities cannot be obtained cheap enough for battery work, but it has been found that if commercial zinc be coated with mercury, which is called amalgamation, pure zinc comes to the surface. This amalgamated coating not only covers the impurities, but it forms a surface which becomes covered by a film of hydrogen when the circuit is open and is thus protected from chemical action while the cell is not in use.

When the circuit is first closed in the simple voltaic cell the electromotive force is stronger than at any other

time. It soon begins to weaken and finally, if the circuit is kept closed long enough, will cease altogether. This diminution in the strength of the current is due to a change that has gradually been going on in the cell, called *polarization*. It is due to several causes, principal of which is the accumulation of hydrogen upon the negative plate. During the action of the cell, the hydrogen which is set free at the negative plate does not bubble up through the liquid and escape, but adheres to the plate, forming in time a complete covering.

Two effects are produced by this film of hydrogen. One is the mechanical resistance which it offers to the flow of current and the other, the electromotive force which it tends to produce. Hydrogen gas is a non-conductor of electricity, and during the action of the cell this gas forms in minute bubbles which increase in number and size till the whole surface of the copper becomes coated. If these bubbles are not disturbed, the action of the cell will cease because there is no longer any exposure of copper.

The second effect produced by the presence of hydrogen on the copper plate is an electro-chemical one. Hydrogen has a greater affinity for oxygen than has the copper, so that there is then an electromotive force established in a direction opposite to that of the cell. The result of these opposing forces is to weaken the cell and its effective electromotive force will be the difference between the two.

The strength of the cell decreases also from a change which has been going on in the electrolyte. The sulphuric-acid solution has been gradually, by the solution

of the zinc, increasing in density by the formation of zinc sulphate. The sulphuric acid is slowly disappearing so that there is less activity at the zinc plate. Moreover, in time the zinc-sulphate solution may reach the copper plate when a coating of zinc will be formed upon it, making the two plates electrically the same, and causing the action to cease.

Since the polarization of the cell by the formation of hydrogen upon the negative is the principal defect in the way of the usefulness of the voltaic cell, there are numerous methods in use for overcoming this difficulty. It is done either by preventing the liberation of the hydrogen directly on the copper plate, or by rapidly absorbing the hydrogen after it is formed. An agent which is used for this purpose is called a *depolarizer* and it is upon this basis that all voltaic cells are divided into two general classes:

1. Cells with depolarizers.
2. Cells without depolarizers.

The cells with depolarizers are capable of furnishing continuous currents for a long time, and for that reason are especially adapted for operating motors, for electroplating, and for some uses in electrotherapeutics. The cells without depolarizers furnish a current which, if the circuit is closed for any length of time, soon drops to zero. These cells are useful for certain kinds of work, such, for instance, as require light current for a short time, but at such intervals that the cell has had time to recuperate. The cells with depolarizers are of a very great variety and may be divided into two classes:

1. Those with liquid depolarizers.
2. Those with solid depolarizers.

Those with liquid depolarizers are capable of giving the strongest and at the same time the most uniform current. The nature of a liquid depolarizer is such that it is always ready and in condition for forming combinations with the hydrogen; whereas, in the case of a solid deporalizer it requires more or less time for the solid to dispose of the hydrogen.

Cells with liquid depolarizers may be again divided into two classes, namely:

1. Single-fluid cells.
2. Double-fluid cells.

The single-fluid cells have a solid depolarizer, whereas the double-fluid cell has its electrodes surrounded by different liquids which are usually kept separate by a porous septum. The porous partition is made of unglazed earthenware and is molded in the form of a cup so as to contain one of the elements and its liquid. This cup is placed in the vessel containing the other element and its liquid. It is sunk deep enough to bring the two liquids on a level. While these liquids do not flow through the cup they mingle in the pores sufficiently to conduct the current. In the double cell one of the fluids is the exciting liquid, and the other the depolarizing liquid.

While the porous cup serves the purpose of keeping the two liquids separate, it offers considerable internal resistance to the current. Since the current follows the liquid through its pores, the formation of bubbles of gas and of salts in the pores increases the resist-

ance to such an extent at times that the cell loses much of its power.

CLOSED-CIRCUIT CELLS.

The first cell to claim our attention is the Daniell from the fact that is was the first constant cell. This cell was invented by Professor Daniell, of Edinburgh, in 1836, and differed from others in use at that time in

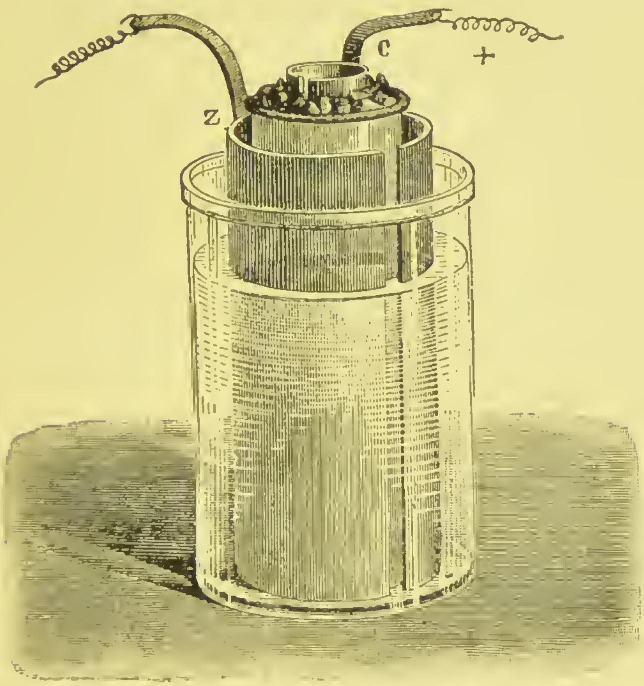

FIG. 17.—DANIELL CELL.

that it was capable of yielding a uniform current for a long time. It made possible from a commercial point of view, the use of the telegraph which had been invented by Morse some four years previous to that time.

This cell is a double-fluid cell with a porous cup.

The elements are zinc and copper and the fluids are zinc sulphate, and copper sulphate. The zinc is in the form of a sheet bent round so as to stand in the containing vessel. Within the zinc is placed the porous cup which contains a smaller coil of sheet copper. A weak solution of zinc sulphate is placed in the outer vessel, and a solution of copper sulphate in the porous cup. Professor Daniell, when first using this cell, found that, while it was an improvement upon other forms of cells, it would nevertheless weaken after constant use. This he found was due to a change which had taken place in the copper solution by a precipitation of the copper, which he overcame by suspending crystals of copper sulphate in a gauze sack. The crystals gradually dissolve, thereby keeping the copper-sulphate solution in a state of saturation.

In some forms of the Daniell cell the above order is reversed. The copper is placed outside and the zinc inside the porous cup, the latter metal being in the form of a rod. The action, however, is the same in either case.

The chemical process which is active in the Daniell cell and upon which its constancy depends is this: The action of the sulphuric acid upon the zinc causes the formation of zinc sulphate and the liberation of hydrogen according to the following equation:

$$Zn + H_2SO_4 = ZnSO_4 + 2H$$

The hydrogen, by a series of molecular changes, migrates toward the copper plate. When the hydrogen passes through the porous cup it meets the solution of copper sulphate which it decomposes, setting free

copper and sulphuric acid. The copper is deposited upon the copper plate and the sulphuric acid passes through the porous cup into the zinc solution. The hydrogen is absorbed in the chemical reaction and never reaches the copper plate for which it began its journey from the zinc plate. As the strength of the copper-sulphate solution declines the crystal salts dissolve, which keeps the solution at about a state of saturation.

The chemical reactions which take place in the Daniell cell may be shown in this way; the formula,

$$Zn + H_2SO_4 + CuSO_4 + Cu$$

represents the condition before the circuit is closed, and after the cell has been in action a change takes place which is represented by the following formula:

$$ZnSO_4 + H_2SO_4 + 2Cu.$$

In this process an atom of zinc is removed from the zinc and an atom of copper has been added to the copper for every molecule of H_2SO_4 decomposed. There is a gradual wasting of the zinc and a proportionate increase of the copper. The zinc compartment becomes laden with zinc sulphate which in time it is necessary to remove.

The Daniell cell, while giving excellent results, is not, however, free from objections. The porous cup answers its purpose best when its pores allow free electrical movement through them. These pores frequently become closed by a deposit of copper. This sometimes occurs to such an extent as to break the jar.

The internal resistance caused by the porous cup limits its application to those uses which require a

small current. The ordinary Daniell cell furnishes scarcely more than an ampere of current.

When the cell is not in use the copper solution diffuses through the porous cup, causing a coating of black oxide of copper to form on the zinc plate, which produces a local action in that compartment. In order to keep this cell in good condition it is necessary to empty the solution when not in use for any length of time.

The E. M. F., (electromotive force) of the Daniell cell is about 1.07 volts.

The Gravity, or Callaud cell is a simplified Daniell cell. The copper-sulphate solution of the Daniell cell was found to be considerably heavier than the zinc sulphate, therefore, instead of separating the copper and zinc solutions by a porous partition, the copper was placed at the bottom and the zinc at the top, and in that way their respective sulphate solutions would, if the cell be kept quiet, form two quite distinct strata with that of the zinc sulphate uppermost. Such a cell is shown in Fig. 18 in which the zinc is suspended from the upper edge of the glass jar and the copper rests upon the bottom.

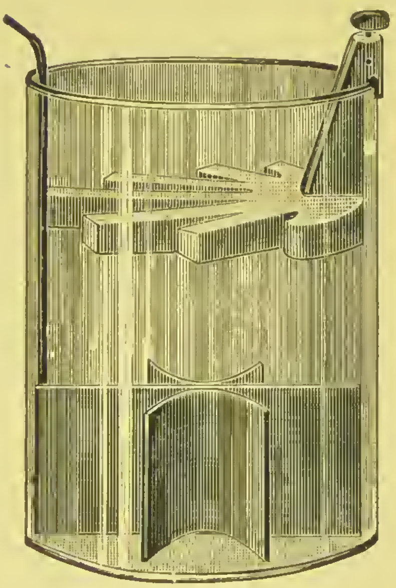

FIG. 18.—GRAVITY CELL.

By this arrangement the porous cup with its dis-

advantages was done away with, and although the electromotive force is not increased, the cell is more constant in its output. The same method is used for keeping this cell in action as in the Daniell cell. A handful of copper-sulphate crystals is carefully let down to the copper plate from time to time, and the zinc solution siphoned off and fresh water added.

There is considerable loss of the solution by evaporation as well as by a precipitation of the zinc salts on the sides of the vessel. Both of these faults may be overcome by covering the liquid with a film of oil.

If this cell is set up with only water and the copper-sulphate crystals, it does not work at first. The outside circuit should be closed and the cell allowed to stand twenty-four hours, when it will be found that the internal action has been sufficient to form the two sulphate solutions about the zinc and copper. If the cell is to be used immediately it is filled half-full of a solution of copper sulphate and the upper half nearly filled with a weak solution of zinc sulphate. Or a more simple method may be employed by adding a little sulphuric acid to the water.

The ordinary gravity cell will furnish one-fourth of an ampere of current steadily, but there are some modifications which are capable of delivering as high as five amperes. The Daniell and gravity cells are the simplest forms of double-fluid cells in use, and the principles employed, and internal actions of these cells are essentially the same as those employed in some of the more complicated forms which need but a description of their construction.

The Gethins Cell.—This is a modification of the Daniell, and is shown in Fig. 19. The porous cup is let in from the top far enough to reach half way down. This cup contains the zinc plate. In the bottom of the vessel is placed the copper disc and copper sulphate.

Fig. 19.—Gethins Cell.

The Minnetto Cell.—This cell is constructed by placing the copper element at the bottom of the jar, and covering this with a layer of copper sulphate. Upon the copper sulphate is placed a sheet of canvas or muslin and upon this a rather thick layer of sand or sawdust. This is covered with another sheet of muslin and a disc of zinc is rested upon the whole. It will also be seen that this cell is a combination of the Daniell and gravity cells in which the porous cup of the Daniell is supplied by the muslin and sand, and the solutions are placed in the proper positions with respect to gravity.

The Delany Gravity Cell.—This is essentially a gravity cell. The copper sulphate is placed at the bottom in a strawboard box, and the copper in the form of a wire is wound around it. The sulphate solution diffuses through the box. The zinc is enclosed in a paper envelope and is suspended in the upper part of the cell. It is claimed that by means of this envelope

copper does not reach the zinc and yet there is the freest electrical interchange.

The Medinger Cell.—This cell consists of a sheet of zinc caught by a construction of the containing vessel half way down. The copper element is placed inside a glass tumbler resting on the bottom of the vessel and the copper sulphate is fed into the tumbler through the glass tube. This cell differs from the Callaud or gravity cell only in the use of the glass tumbler.

We now come to a class of cells which differ from the Daniell and Callaud cell in the elements, exciting liquids, and depolarizers that are used. Copper, zinc, and sulphuric acid are not the only agents that are available for producing an electric current. Electricity is present in all chemical processes, so that there remains simply the work of grouping and arranging as to detail the processes and appliances whereby the greatest amount of electric energy can be realized with the least expenditure of material. There is an endless variety of agents and combinations which may be employed for producing electric currents, and these will at the same time produce currents which have a wide range as to voltage and amperage. All the uses to which electricity is applied are not the same, so that it is quite convenient to select a combination of elements and excitants to meet the requirements of each one.

In nearly all these combinations zinc is retained as the positive element, and there is but very little change in the negative element. The copper is generally supplanted by carbon. The greatest variation is found in the electrolyte. This, as before stated, may be a single

or double fluid, and it may range all the way from a strong acid to a marked alkali.

The Grove Cell.—The Grove cell is made up of zinc and platinum elements with zinc-sulphate and nitric-acid solutions. It is a double-fluid cell with an earthenware septum. The zinc is a thick sheet bent in the form of the letter U. The porous cup contains a sheet of platinum and is flat enough to stand within the U-shaped piece of zinc. The form of the zinc is sometimes modified so as to surround the porous cup. Zinc sulphate surrounds the zinc and nitric acid fills the porous cup. This cell is shown in Fig. 20.

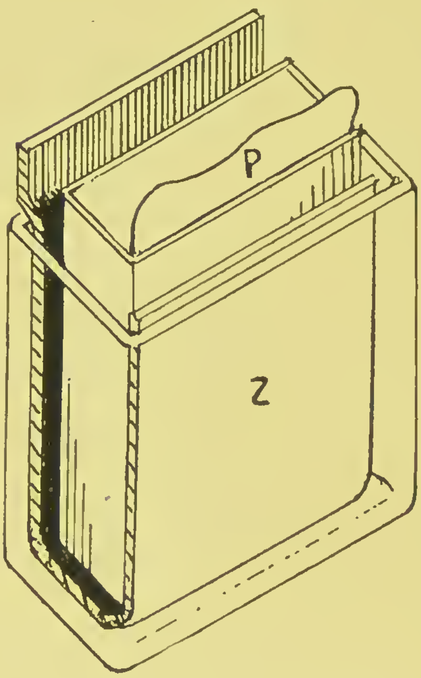

FIG. 20.—GROVE CELL.

When the Grove cell is in action the zinc is dissolved, forming, as in the gravity cell, zinc sulphate. The hydrogen on passing through the porous partition, is oxidized by the nitric acid and does not reach the platinum for which it started. In this capacity the nitric acid acts as a depolarizer. There is no action on the platinum plate. The nitric acid, by taking up the hydrogen, undergoes a series of decompositions in the following order: HNO_3, nitric acid; HNO_2, nitrous

acid; HNO, hyponitrous acid, and finally NO_2, nitrogen peroxide, a highly poisonous gas is formed by the escape of NO in the air. The hydrogen has united with oxygen forming two molecules of water, $(2H_2O)$.

It will be seen that the continual formation of water weakens the solution in the porous cup. This in time may produce another form of reactions. The acid may give up all its oxygen, forming ammonium nitrate.

The internal resistance of the Grove cell is very little so that a rather high E. M. F. is operative. When in good order it gives nearly two volts. When this cell is in use the corrosive gas arising from it should be conveyed to the open air. When not in use it should be taken apart.

The Bunsen Cell.—This is a modification of the Grove cell. The sheet of platinum is replaced by a block of carbon which is not only much cheaper than the platinum, but, being quite rough, presents a much larger surface.

Iron is sometimes substituted for the carbon, but when the acid becomes weakened the iron is frequently attacked. In order to avoid the poisonous fumes chromic acid and dilute sulphuric acid are sometimes substituted for the nitric acid.

The E. M. F. of the Bunsen cell is about the same as the Grove, or 1.9 volts.

The Gordon cell.—This, as shown in Figs. 21 and 22, has copper and zinc elements with a sodium solution. A metal cover fits the top of the jar through the middle of which is let a copper rod which supports the copper

element inside and at the same time answers for a binding post on the outside.

The copper element which is perforated is suspended in the middle. Outstanding from this are three porcelain knobs which support a cylinder of sheet zinc. An insulated wire passes from the zinc through an insulating bushing in the cover.

FIG. 21.—GORDON CELL WITH JAR.

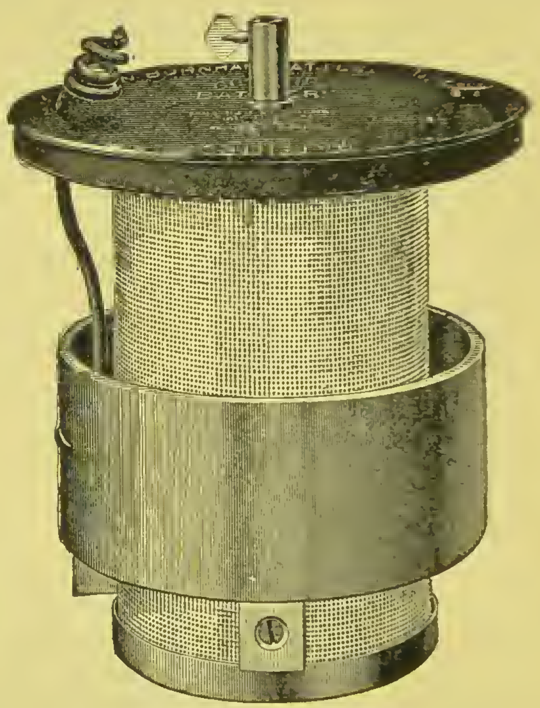

FIG. 22.—GORDON CELL WITHOUT JAR.

The Fuller Cell.—Chromic acid is a strong oxidizing agent, and this property makes it useful for battery purposes. If sulphuric acid be added to the bichromate of potassium or sodium, there will be formed the sulphate of potassium or sodium and chromic acid. If we take bichromate of potassium as an example, the action would be represented by the following:

$$K_2Cr_2O_7 + H_2SO_4 = K_2SO_4 + H_2O + 2CrO_3.$$

In those cells which employ the bichromate solution, chromic acid is the oxidizing agent and prevents polarization by uniting with the hydrogen.

The Fuller cell uses as one of the electrolytes, bichromate of potassium, and for this reason it is sometimes called the *bichromate cell.* A block of zinc rests on

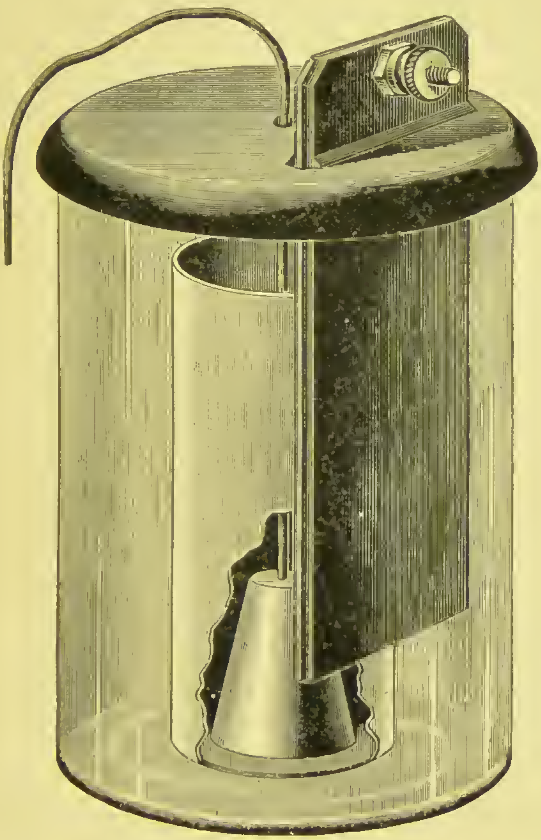

FIG. 23. FULLER CELL.

the bottom of the porous cup, and, to insure continuous amalgamation of the zinc, the bottom of the cup is covered with mercury. The porous cup stands at one side of the containing vessel and a carbon block at the other.

The porous cup is nearly filled with water and the bichromate solution is brought to the same level in the outer vessel. A Fuller cell is shown in Fig. 23.

The solution for the bichromate cells is made up in the following proportions:

Bichromate of Potassium	1 part.
Sulphuric Acid	2 parts.
Water	20 parts.

The bichromate must be heated in boiling water to effect perfect solution. The acid is slowly added to the water, and when both solutions are cool they are to be mixed, and the fluid will be ready for use.

The chemical reaction which takes place may be represented as follows:

$$K_2Cr_2O_7 + 7H_2SO_4 = 2CrO_3 + K_2SO_4 + H_2O + 6H_2\,SO_4.$$

When this solution is placed in the cell we would have the following formula:

$$3Zn + 7H_2SO_4 + K_2Cr_2O_7 + C.$$

When the cell is in action the chemical process in progress produces chromium sulphate, zinc sulphate, and water, represented as follows:

$$2CrO_3 + 6H_2SO_4 + 3Zn = Cr_2\,3(SO_4) + 3ZnSO_4 + 6H_2O.$$

The bichromate cell has a low internal resistance, and gives nearly two volts' pressure. There are no acid fumes arising from it, and where a strong current is desired for a short time, this form of cell is one of the most convenient.

Bichromate of potassium has been generally used in this class of work, but sodium bichromate is recommended instead. The advantages of this salt over the

potassium according to Professor Carhart, are as follows:

1. It contains a larger percentage of available oxygen.

2. It is much more readily soluble and requires no heat.

3. The sulphates if they should form do not crystallize but remain in solution.

The Partz Acid Gravity Cell.—This cell has been selected by the S. S. White Dental Manufacturing Company for dental purposes, and being unique in its construction is worthy of a somewhat minute description. As is indicated by its name, it is a gravity battery, although in some of the forms a porous cup is used. It also resembles the Bunsen cell, but the details have been so much improved that it has received a new name. It employs the gravity principle for the separation of the fluids of the electrolyte, and uses an acid depolarizer.

The cells without a porous cup consist of a carbon block which rests upon the bottom of the containing vessel. This block is either perforated with a number of holes or has a number of projections thereon which in either case increase the surface of carbon. The other element is of zinc and is suspended from the top in the form of a "crowfoot" or a broad plate.

Whenever the porous cup is used the pores of the lower half are filled with paraffine so as to prevent the mixture of the two solutions below the middle line. The zinc in the form of a cylinder stands within the porous cup.

The exciting liquid for this cell which is to be placed in contact with the zinc may be a solution of either sulphate of magnesium or of common salt. The solution of salt is a much better conductor.

FIG. 24.

The depolarizing solution is to be placed at the bottom. This is furnished in the form of a sulpho-chromic salt. It is in a crystalline state and is sealed in glass jars containing two pounds each. It is readily soluble in water and should be dissolved in six pints of water to give it the proper strength for this work. This being heavier than the zinc solution, remains at the bottom.

A novel feature of the Partz cell is the use of a glass funnel which reaches almost to the carbon. By this means the strength of the sulpho-chromic solution can be maintained by dropping the salt in the funnel which reaches the heavier solution without mixing with the upper and lighter solution.

An illustration of the simplest form of the Partz cell is shown in Fig. 25.

This cell gives almost two volts' pressure and when used for heavy work such as operating an electric motor, or for plating, is supplied in a square form and gives about five amperes.

The Partz cell in which a porous cup is used, gives a little higher voltage, but the internal resistance produced by using the porous cup lowers the strength of the current. Such a cell is shown in Fig. 26.

This cell is best adapted for bells, gas-lighting and all light work.

A cell which the manufacturers call Partz Motor Cell is especially designed for heavy work. It is square in form and employs the porous cup. The car-

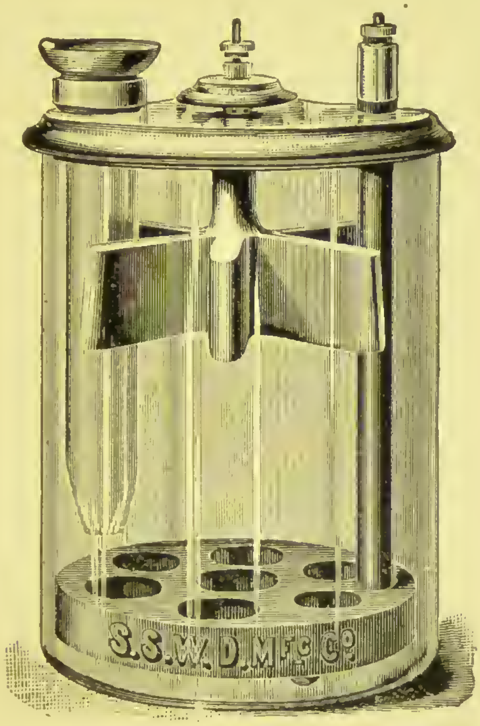

FIG. 25.—PARTZ ACID GRAVITY CELL.

bon is in five blocks which are deeply corrugated. These are arranged around the porous cup and fastened at their upper ends to a metal strip. Within the porous cup is the zinc element. This cell is shown in Fig. 27, and gives two volts and from ten to twelve amperes on short circuit. Thirty such cells will deliver one-eighth electric horse-power for thirty hours' continual use on a single charge. This in actual practice should last from two to six months.

Where the dentist has not the advantages of the commercial current the Partz Acid Gravity Cell will, all things considered, meet his requirements as well as, if not better than, any other form of primary battery.

The bichromate of potassium or preferably of sodium is also employed in cells with the plates arranged per-

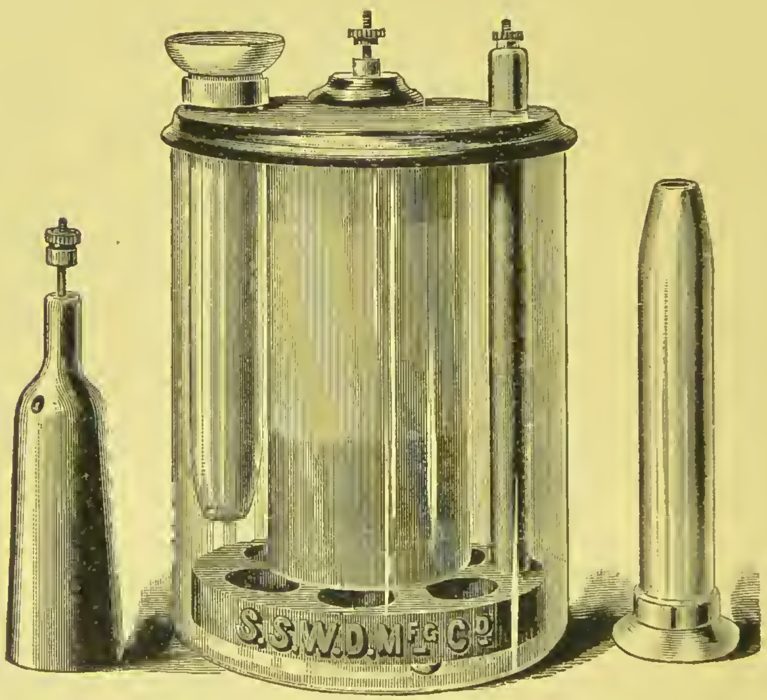

FIG. 26.—PARTZ CELL WITH POROUS CUP.

pendicularly. Both being excitants and depolarizers, the zinc and carbon plates may be placed side by side and dipped in the bichromate solution. This form of cell is called the Grenet, as shown in Fig. 28.

If several cells are compactly arranged so that all the elements can be raised or lowered at once it is called a plunge battery. This is shown in Fig. 29.

The plunge battery is useful principally because there will be no useless waste of material, and because it can be readily and easily adapted to the demands put upon it. It is especially useful in conjunction with bichromate batteries of the Grenet principle.

While the best depolarizers are liquid there are other agents which in the solid state are acted upon by hydrogen. The oxide of copper and the chloride of silver are two agents most frequently used for this purpose. When they are used the cells are single-fluid cells. The positive element, as in other cases, is zinc.

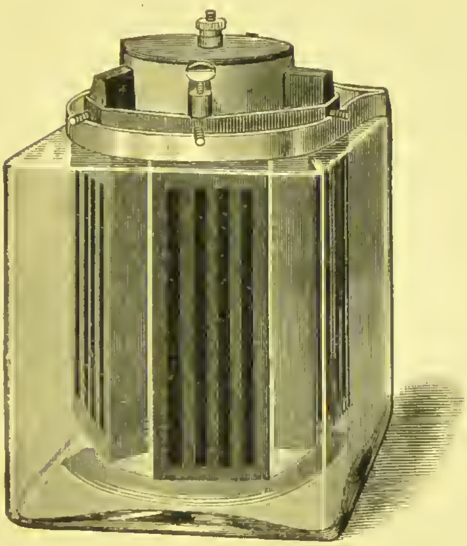

FIG. 27.—PARTZ MOTOR BATTERY.

The chemical process which takes place in this form of depolarizer is this: The oxygen of the copper oxide unites with the hydrogen, and the copper appears in the metallic state. Or, if chloride of silver is used, the hydrogen and chlorine unite, and the silver appears in its metallic state.

The Copper-Oxide Cell was invented by Lelande and Chapernon. It consists of a zinc element in the form of a coil suspended from the top of the vessel. On the bottom rests an iron cup containing oxide of copper. This is the negative element. Recently this cell has

been modified, and it is now called the Edison-Lelande Cell. The improved cell consists of a glass or porcelain vessel somewhat larger than the ordinary cell. Two plates of zinc are let down from the cover, and between these two plates is suspended a plate made of compressed copper oxide, care being taken that this cannot make contact with either of the zinc plates. The electrolyte is a forty per cent. solution of caustic potash or soda. Such a cell is shown in Fig. 30.

Fig. 28.—The Grenet Cell.

When the Edison-Lelande Cell is in action, the caustic alkali is decomposed with the formation of the zincate of soda or potassium as the case may be. The hydrogen unites with the oxygen and the copper oxide is reduced to metallic copper.

Since there is a large exposure of zinc and the copper-oxide plate is in close proximity, the internal resistance is very little, and such a cell will give a rather heavy current. The voltage, however, is comparatively low, being less than

one volt. A thick film of heavy oil should always cover the solution in these cells.

The Chloride of Silver Cell.—A cell differing somewhat in form and construction from most of those in use is the chloride of silver cell. It consists of a rather small glass vessel with a cork fitting the upper end. A rod of zinc extends from the bottom of the vessel up and through one side of the cork. The negative element is a wire or ribbon of silver around which a cylinder of silver chloride is cast. The electrolyte may be a dilute solution of sal ammoniac, a solution of common salt or zinc sulphate. This cell is shown in Fig. 31.

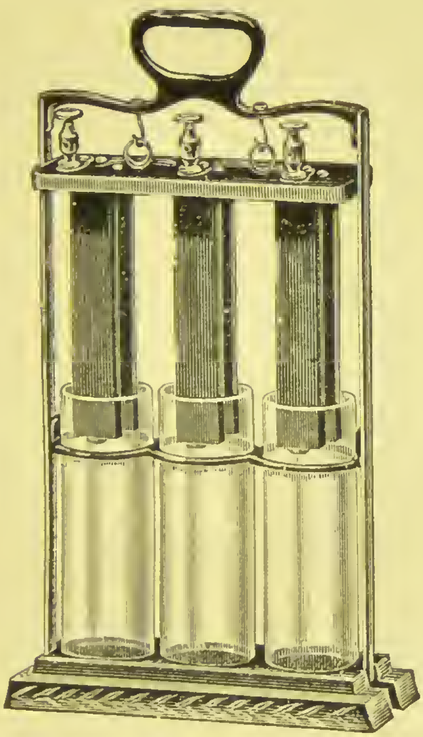

FIG. 29.—PLUNGE BATTERY.

When the chloride of silver cell is in action, the hydrogen unites with the non-metallic element and metallic silver appears. It gives an E. M. F. of 1.1 volts. On account of its small size, it does not give a very large current, but its compactness and quite uniform action make it especially adapted for portable work and testing. In dentistry it would be most suitable for cataphoric purposes.

OPEN-CIRCUIT CELLS.

The term "open circuit" applies to those cells which are so constructed that they furnish a good current for a short time, but if the circuit be closed for any length of time the current becomes very weak and may cease altogether. Some of these cells do not show this diminution as quickly as others, and even when their pressure has dropped, they promptly recover. On the other hand there are some which on closing the circuit quickly diminish in power, and on opening the circuit do not recover for a long time. Those cells which recover promptly are generally supplied with a depolarizer, but, as stated at the beginning of this chapter, the best depolarizers are liquid because they are capable of more quickly entering into chemical combination with the hydrogen. The other class of depolarizers is solid. They are slow in action and do not quite keep pace with the formation of hydrogen, so that sooner or later the cell is weakened by the formation of hydrogen in excess of that liberated or occluded by the solid depolarizer. These cells are fitted only for such uses as employ a current for a short length of time and with intervals of rest.

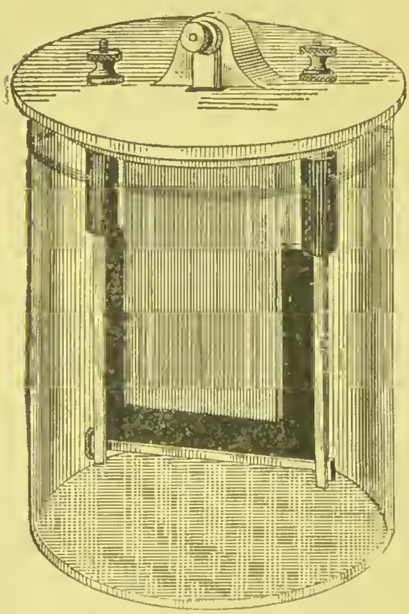

FIG. 30.—THE EDISON LELANDE CELL.

In the practical use of some cells they are expected to stand for months and even years in some cases, and still be able to furnish a current at any time. In order to do this it is important that there shall be no internal action when the circuit is open and when the cell is not in use. These conditions are met in most of the open-circuit cells by the employment of a solid depolarizer. This type of cell forms an intermediate class between those cells without depolarizers and the closed-circuit cells described in the first part of this chapter. When the depolarizer is a liquid, or a double liquid, there is great danger of diffusion during the intervals of rest. This fault is overcome by the use of a depolarizer which is a solid and which is not affected by the electrolyte.

FIG. 31.—SILVER CHLORIDE CELL.

The material used as a depolarizer in the open-circuit batteries varies as much, perhaps, as the exciting liquid in closed-circuit cells. The sulphates and chlorides of mercury, the chlorates of potassium and sodium, and the peroxide of lead, have been employed for this purpose, but the black oxide of manganese is the one most generally used. Whenever such a substance is employed in a

cell, it takes the place of a second liquid by oxidizing the hydrogen before it reaches the negative plate.

The Leclanche Cell.—There are two divisions of cells, each having its typical representative. The closed-circuit cell is represented by the gravity cell, which has been described, and the open circuit is represented by the Leclanché which will now be taken up.

FIG. 32.—LECLANCHE CELL WITH POROUS CUP.

The Leclanché cell takes its name from its inventor, Leclanché, a French electrician. The cell is constructed with and without a porous cup. When the cup is used at all, it is for the mechanical purpose of a containing vessel for the depolarizing compound, and not as a partition for separating two liquids. A Leclanché cell

with a porous cup is shown in Fig. 32. A block of carbon is placed in the center of the porous cup, and around it is packed manganese dioxide and graphite or powdered gas carbon which have been thoroughly mixed together. The porous cup is then sealed by pouring melted pitch on the top of the powdered carbon and manganese. It is a wise provision to puncture the layer of pitch so as to permit the free escape of gas. The porous cup is then placed in a glass jar.

The positive element of the Leclanché cell is a rod of zinc which stands alongside the porous cup, and the electrolyte is a strong solution of sal ammoniac.

If the zinc and sal ammoniac are pure no change will take place on open circuit even after months of standing; when the circuit is closed, however, a chemical action ensues. The zinc is attacked by the chlorine of the ammonium chloride, and ammonium and hydrogen are liberated. The excess of ammonia over that taken up by the solution escapes. The hydrogen starts for the carbon plate, but on reaching the manganese is oxidized and water is formed.

The chemical reaction may be represented as follows:

On open circuit:

$$Zn + 2NH_4Cl + 2MnO_2 + C.$$

On closed circuit:

$$ZnCl_2 + 2NH_3 + MN_2O_3 + H_2O + C.$$

The other form of Leclanché cell is one which does not employ the porous cup. As stated before, the porous cup acts only as a mechanical receptacle for the pur-

pose of holding manganese dioxide about the carbon plate. The solution is the same on either side of the porous wall, so that there is no object in separating the fluids, and if the cup can be omitted the resistance will be less.

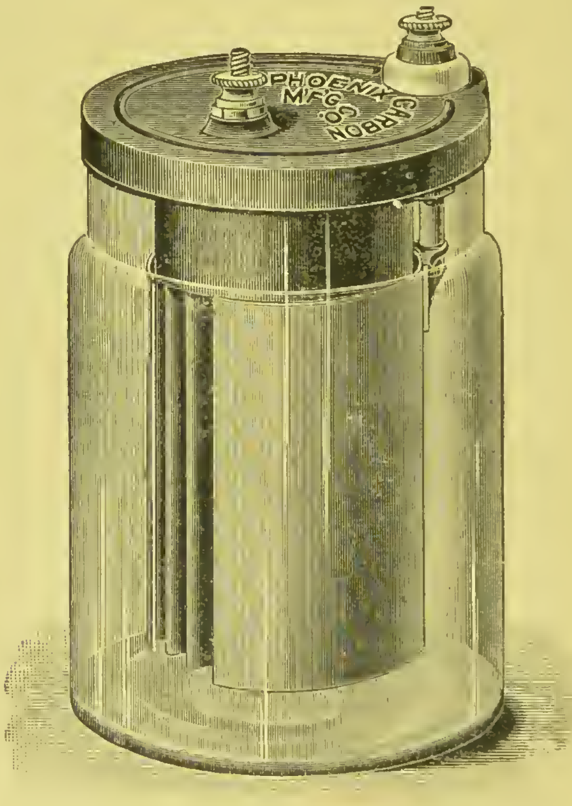

FIG. 33.—LECLANCHE CELL WITHOUT A POROUS CUP.

In order to do this, the manganese dioxide must be held in contact with the carbon by some other means. Instead of the manganese being loosely mixed with powdered carbon, it is found that it can be incorporated in the carbon block at the time of its manufacture, and answer the purpose of an oxidizer almost as well. Such a cell is shown in Fig. 33.

The zinc instead of being in the form of a rod is a sheet which surrounds the carbon block. This large exposure of surface and its proximity to the carbon materially decreases the internal resistance.

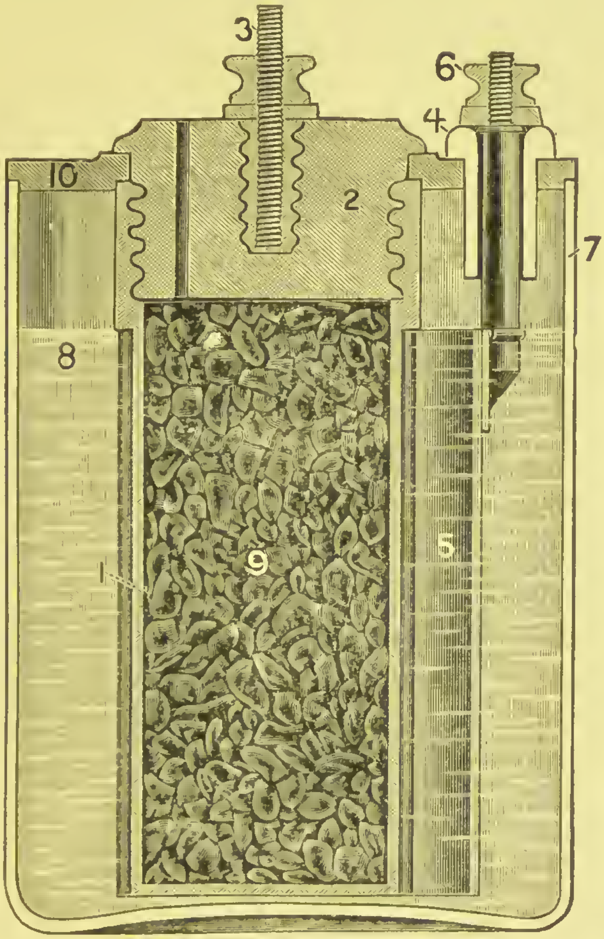

FIG. 34.—CARBON POROUS CUP CELL.

When the carbon containing the manganese dioxide, sometimes called agglomerated carbon, is used, the depolarization is not as rapid as where the porous cup is employed. This is due to the fact that in the agglomerated form the structure is much more dense than where

the manganese is loosely mixed with the graphite. The slow depolarization of this form of cell is compensated, however, by the reduced internal resistance of the battery, and by its simple construction.

The Phœnix Carbon Company has a Leclanché cell upon the market which is illustrated in Fig. 34.

At first sight, it appears to be of the class of cells previously described, namely, cells with a porous cup: but in this case the cup is composed of carbon, and, since it contains carbon, it has not the function of a partition like

FIG. 35.

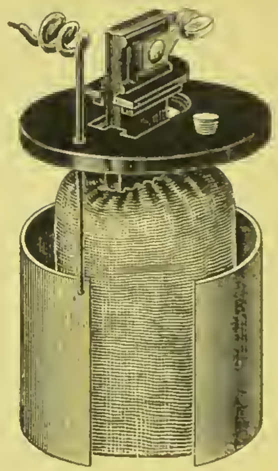
FIG. 36.

that afforded by earthenware but is a receptacle for containing the depolarizer. Manganese and powdered carbon fill the carbon cup. The advantages claimed for this cell are its efficiency and ease of renewal. It is an easy matter to refill the carbon cup with fresh manganese and carbon. The carbon of the containing cup is quite porous, so that there is free interchange through its walls. The zinc element is in the form of a sheet which surrounds the carbon element at a short distance from it.

The Vole cell as shown in the next two figures has just the opposite arrangement as to the carbon element and the depolarizer. The carbon is in the center, and surrounding it is the depolarizer which is contained in a bag. This also permits of free circulation of the fluid.

FIG. 37.—LACLEDE CELL.

The cells just described will give a current of about one and one-half volts' pressure at first, but the average working pressure is about one volt. This class of cells is best suited for work which requires small current for a short time such as ringing a bell or the operation of an annunciator. Its use in dental practice

would be for such work as cataphoresis or the operation of an electric mouth lamp. Since the cautery and root-dryer usually require but a few minutes for each operation, a few Leclanché cells, if large enough, will furnish sufficient current.

There is an endless variety of open-circuit cells now upon the market. Most of these are essentially Leclanché cells. The carbons and agglomerated carbons assume a variety of shapes, and the zinc modifications are no less numerous, but the effort is principally made in the direction of increasing the carbon surface and at the same time keeping the cell as compact as possible.

OPEN-CIRCUIT CELLS WITHOUT A DEPOLARIZER.

This form of cell, except one of its peculiar modifications, the dry cell, is of very little commercial importance. The dry cell possesses a feature which adapts it to certain kinds of work better perhaps than any other form. This and the chloride of silver cell are the only ones that are suitable for portable work.

The elements used in this class of cells, with one or two exceptions, are carbon and zinc, and generally the efficiency of the cell depends upon the size and condition of the surface of the carbon plate. By this is meant the ability of the carbon plate to either set the hydrogen free in bubbles or to present so large an area of surface that it will take some time for the hydrogen to accumulate in such quantities as to interfere with the working of the cell. This is sometimes called the Laclede cell, and is shown in Fig. 37.

The Smee Cell.—This cell is one of the oldest

forms, and was invented in 1840 by an English electrician from whom it takes its name. This, as shown in Fig. 38, consists of two sheets of zinc forming the positive electrodes between which is suspended a metal plate covered with platinum. The middle plate was originally made of silver which was platinized. This being expensive, led to the discovery that a sheet of copper answered for the bulk of the middle plate. This was roughened by an electro-deposit of copper upon it. A deposit of silver was then added and finally, upon this, one of platinum. By this means the plate is cheapened, and at the same time made a better conductor. The object of roughening the platinum surface is to mechanically dislodge the hydrogen. A gas under these conditions will rise from a sharp point more quickly than from a smooth and flat surface.

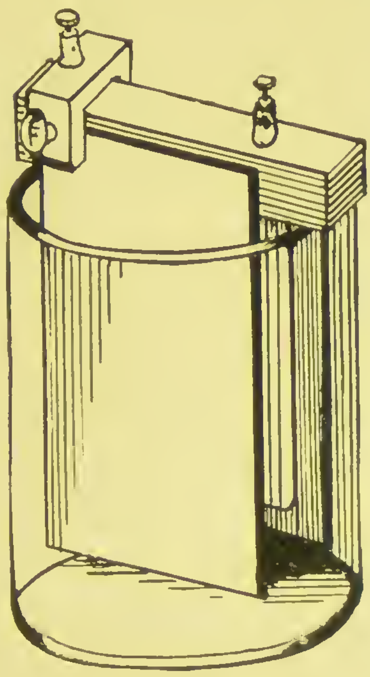

FIG. 38.—SMEE CELL.

The electrolyte employed in the Smee cell is a dilute solution of sulphuric acid. When the circuit is closed this acts upon the zinc, forming zinc sulphate about the zinc electrode, and liberating hydrogen at the platinized plate according to the following equation:

$$Zn + H_2SO_4 = ZnSO_4 + 2H.$$

The Smee cell gives an electromotive force of scarcely more than half a volt, and since the only method employed for the management of the hydrogen is mechanical, viz., the employment of a rough surface, it is evident that but a short time will elapse until the whole surface will become completely covered with hydrogen and activity will cease. Such a cell is fitted only for open-circuit work.

The Law Cell.—In the effort to find a substitute for the expensive platinum-covered plate of the Smee cell, carbon was employed. This formed a type of zinc-carbon cells without depolarizers, of which the Law cell is an example. Instead of using a rough surface of platinum for the purpose of mechanically setting free the hydrogen, a large block of carbon is employed. The efficiency of such a cell depends entirely upon the extent of carbon surface exposed, and the condition of the surface of the carbon. The carbons used in all of this class of cells are either very large in bulk in proportion to the zinc or if small are deeply grooved. In either case they present a considerable surface for the liberation of the hydrogen. An advantage is gained in having the surface of the carbon as rough as possible so that the hydrogen will escape more easily.

The Law cell shown in Fig. 39 has a very large cylinder of carbon the ends of which do not quite meet. Within this cleft stands a rod of zinc. Very frequently the cell is supplied with a second carbon cylinder which is suspended in the center.

The amount of surface afforded by the zinc rod is

not very large, and it is not necessary that it should be, for the reason that one much larger in proportion to the carbon would furnish so much zinc for chemical action that the waste products would not be taken care of economically. In other words, the hydrogen developed from the action on a larger quantity of zinc would be more than could be disposed of properly by the carbon surface. The capacity of such a cell depends entirely upon the area of carbon surface and the condition of that surface. A small bit of zinc will give rise to a very large quantity of gas, and it may be stated that in the practical working of a Law cell the area of zinc should be one-fiftieth that of the carbon, in order that the latter may properly dispose of the hydrogen that is generated.

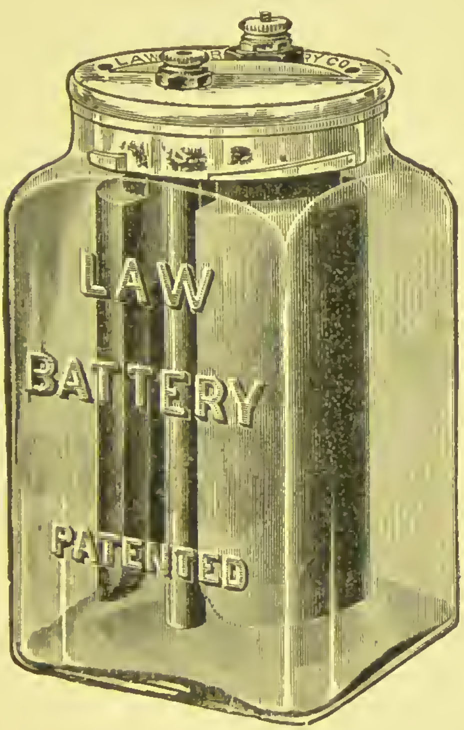

FIG. 39.—THE LAW CELL.

The electrolyte employed in the Law cell is a solution of sal ammoniac, six ounces to a quart of water. If the zinc is without impurities, it may stand in the above solution almost indefinitely and no action will take place but, if the external circuit be closed, the sal-ammoniac

solution will be decomposed, chlorine acting on the zinc, forming zinc chloride, and hydrogen will be liberated at the carbon plate.

In practice, the electromotive force of the Law cell, like all others of this type, scarcely exceeds one volt.

A serious objection to all batteries is the loss of the electrolyte by evaporation and the creeping of the salts. These are both in a measure overcome by covering the solution with a film of heavy oil. The same end can be accomplished by hermetically sealing the cell. This is done in a cell recently put upon the market under the

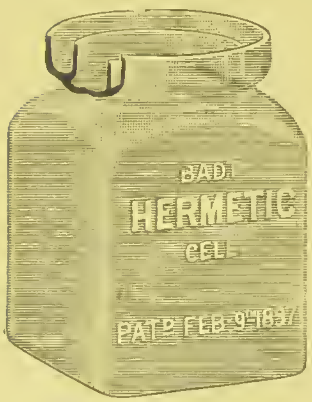

FIG. 40.—JAR WITHOUT COVER.

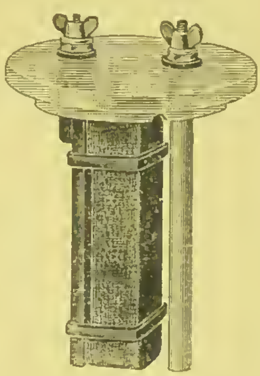

FIG. 41.—COVER WITH DEPOLARIZER.

FIG. 42.—COVER WITH OUT DEPOLARIZER.

name of the Badt Hermetic cell, which is illustrated in Figs. 40, 41, and 42.

The glass jar contains a deep groove around the mouth into which a circular projection from the under surface of the lid is received. The groove in the jar is then filled with heavy oil which makes a hermetic sealing of the cover and still allows escape of gas from within. The lid is of glass and the connecting posts of each element are sealed where they pass through the

glass by rubber washers which are tightly compressed above and below by means of a hexagonal nut.

The cell is made up with or without a depolarizer. Fig. 41 shows a cover with a depolarizer and Fig. 42 one without. The carbon of the one without the depolarizer is of large surface and is fluted on the inside.

FIG. 43.—A DRY CELL.

The Dry Cell.—This type of cell has come into favor largely on account of its cleanliness and portability. The first of these cells was called the Gassner dry cell, from Doctor Gassner. They are now to be had under as many names as there are manufacturers of them. This is not, strictly speaking, a dry cell. There can be no electrolytic action where the electrolyte is dry. In this case the electrolyte is in a semi-fluid state, moist enough to supply the conditions for electrolysis and yet not fluid enough to escape upon reversing the cell. The complete cell is usually about three inches in diameter and six or eight inches high. It is made of a thick sheet of zinc which at the same time serves as the positive electrode. It is not supplied with a top or cover but at one side is attached a binding post.

The electrolyte in the form of a thick paste is filled in the zinc can to a point about an inch from the top. A carbon plate two inches wide and the same length as the cell is then pressed down in the center of the paste till it is within an inch of the bottom. In order to fix

the carbon in its position and seal the paste, melted pitch is poured in the remaining space. The carbon now stands an inch higher than the zinc and to this projecting portion is attached a binding post.

The electrolyte employed in a dry cell usually consists of a strong sal-ammoniac solution made into a thick paste by the addition of starch. In some cells, however, the paste consists of:

Oxide of Zinc	1 part.
Sal ammoniac	1 part.
Chloride of Zinc	1 part.
Plaster	3 parts.
Water	2 parts.

The electromotive force of the dry cell is 1.3 volts. The current supplied by this cell may begin with six or eight amperes on short circuit, but if the circuit be kept closed there is a rapid drop. The dry cell is recommended for those uses which employ small current and is especially suitable where cleanliness is essential, or where a portable cell is desired.

The size of the cell used in primary batteries varies somewhat, and yet, except the chloride of silver cell. the range of size in nearly all commercial cells is between a quart and a gallon measure. The increase in the size of the cell only increases the volume of current in amperes. The voltage of the same class of cells is the same irrespective of the size. A cell the size of a thimble will give as high voltage as one as large as a barrel. This is because the voltage depends upon the chemical process, and chemism, if the material and conditions are proper, takes place irrespective of the size of the vessel containing the elements. The chloride of

silver cell will give a little over one volt pressure, and yet a Smee cell one hundred times as large can only furnish half a volt. This is due to the elements which make up the electrodes, and to the action of the electrolyte upon them.

While the increase in the size of the cell does not affect the voltage it does increase the volume of current in amperes. The quantity of material being transformed by the chemical process into lower compounds, heat and electricity, is the measure of the current that will be produced. A small quantity of zinc being acted upon by sulphuric acid gives a very small current, while a large piece of zinc being acted upon will give a proportionately large amount of current. The relation between the size of the cell and the output of current may be summed up in a few words by saying that the activity of the chemism determines the voltage of the cell, and the quantity of material consumed in the chemical reactions, determines the current in amperes.

THE BATTERY.

When a number of cells are connected for producing a current they are called a battery. The arrangement of these cells is governed by the use for which the battery is employed. In general, there are two methods of grouping the cells: one is in *series* and the other is in *parallel*. A somewhat complicated plan is followed for some purposes which is a combination of the two and is called the *series-parallel*.

When the zinc plate of the first cell is connected to the carbon of the second, and the zinc of the second to

the carbon of the third, and so on, as shown in Fig. 44, the cells are connected in series.

If, however, instead of connecting the carbon of one

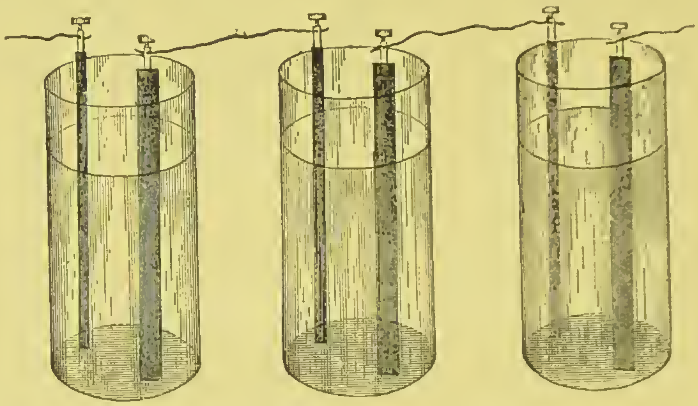

Fig. 44.—Cells Connected in Series.

cell to the zinc of the next, the carbons of all three cells are connected to one wire and the zincs to another as shown in Fig. 45, the cells will be connected in parallel.

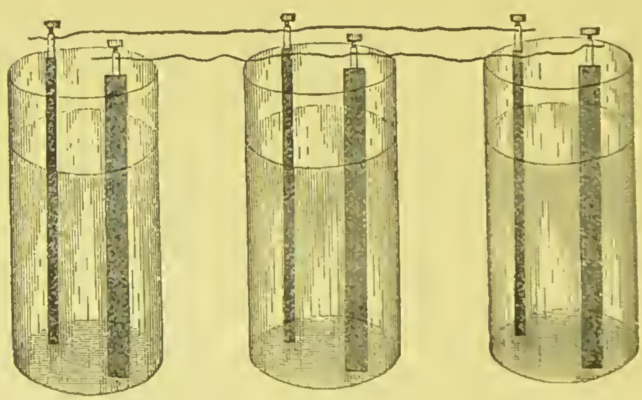

Fig. 45.—Cells Connected in Parallel.

The amount of work done by either arrangement of the connections will be the same. So long as either system of wiring is carried out through all the cells, the number

of watts, (the product of the volts into the amperes,) will be the same whether the cells are connected in a series or in parallel. There is, however, this marked difference in the character of the current produced by the two methods of connecting. If the cells be connected in series, the current produced will be high in voltage, but low in amperes, and if they are connected in parallel the current will be high in amperes and low in pressure. When the cells are connected in series, the electromotive force of each cell is added to that of the others so that we get a current whose voltage is equal to the sum of the voltages of all the cells. The impulse given the current on leaving the first cell is retained, and from each succeeding cell through which it passes it receives an additional impulse. If one cell gives an electromotive force of two volts, six such cells connected in series will give twelve volts.

When cells are arranged in parallel by connecting all the zincs to one wire and all the carbons to another, we have practically but one cell, but a very large one. The electromotive force is not augmented by each additional cell as in the previous arrangement, but the amount of current in amperes is increased. The reason for this is that each zinc has the same electric potential in the same kind of cells, and when they are all connected as in the parallel arrangement, there can be no rise in potential. Each zinc, however, is undergoing solution and the current in amperes arising from this flows into the common conductor for the whole set of cells. In this way the output of the cells of the parallel battery is one more largely of amperes than of volts.

The difference between the series and parallel methods of connecting the cells may be illustrated by supposing each cell to be a tank of water. If these tanks be placed one upon the other and then connected by tubing from one to the other, the pressure felt at the opening from the one lowermost will be three times as great as before. This will represent the series arrangment of cells and the method employed for getting current of high voltage. Now place the three tanks side by side with their respective outlets leading into a main. The pressure at each outlet will be only one-third as much by the above arrangement, but, there being three such outlets, there will be a larger volume of water flowing. This represents the parallel arrangement of the cells and the work which can be done by it will be equal to that by the series arrangement.

THE DYNAMO.

The production of an electric current of commercial value is due to the invention and perfection of the dynamo. The incandescent and arc lights, the motive power for railways, for factories, and for private purposes, as well as the heavy currents employed in welding, in electrolysis, and for electroplating, are all supplied by currents generated by the dynamo. The currents supplied by the thermopile and the galvanic battery are feeble indeed when compared with the possible output of the dynamo. In fact, the dynamo current is limited only by the mechanical problems of heavy machinery. The dynamo as it is to-day perfected, is a remarkable invention, for it is capable of converting

ninety-seven per cent. of the energy supplied it into electricity.

The dynamo is the outgrowth of two discoveries. The first and more important was made by Faraday in 1831, when he found that an electric current was generated in a conductor when it was moved across a magnetic field. The second was the discovery in 1866 that the substitution of electromagnets for the permanent magnets of the field very largely increased the output of the machine. Faraday announced that "when a conductor is moved in a magnetic field so as to cut the lines of force, there is an electromotive force induced in the conductor, in a direction at right angles to the direction of the motion, and at right angles also to the direction of the lines of force." If a piece of wire be passed in front of the poles of a horseshoe magnet, it will demonstrate the above announcement of Faraday and that is practically what we have in the magneto-machine of to-day. It is simply one of induction. The wire cuts the lines of force of the magnet and in so doing a current of electricity is set up in the wire.

It is not the best method mechanically to rapidly pass a wire back and forth by a reciprocating motion; but if the wire be mounted on a spindle in such a manner that by the revolution of the spindle the wire is passed in front of the magnet with each revolution, a very rapid movement can be obtained and a current will be produced in the wire which will be proportionate to the speed of the spindle. When so arranged it is essentially what is known as the armature of the dynamo, and it becomes more efficient, if the spindle upon which the

wire is wound be of soft iron so as to form part of the magnetic circuit. The revolving wire with its iron core is then an electromagnet with the wire wound longitudinally. These are the principles embodied in Faraday's discovery. They were employed in a practical form in the machines used up to 1866 and are to-day known as the faradic or magneto. The simple faradic machine is shown in Fig. 46. This is used for giving a light alternating current for experimental purposes.

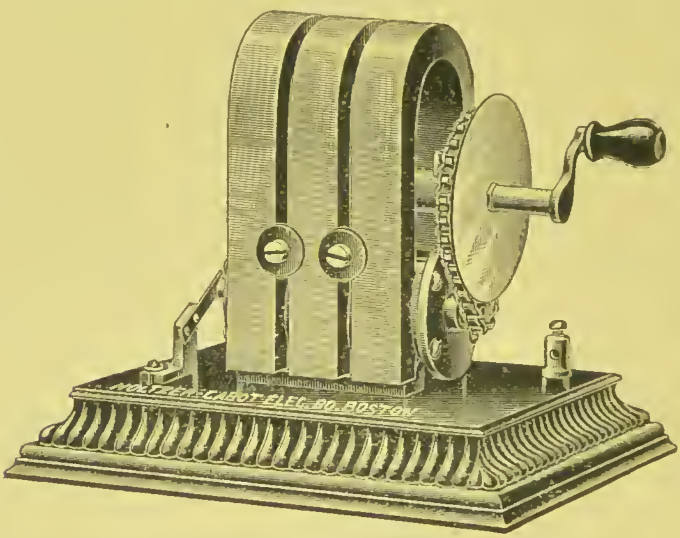

FIG. 46.—THE MAGNETO.

The most practical use made of the magneto is in telephone service, where it is employed to ring the bell. The inside of a telephone with the magneto is shown in Fig. 47.

The magneto-dynamo consists of three parts: the field, armature, and commutator.

The distinguishing feature of this machine lies in the field. This is a permanent magnet, and the effi-

ciency depends upon the strength of its magnetization. The output of the magneto is limited by the degree to which the permanent magnet is magnetized. When new, it is magnetized to saturation and the machine is quite efficient; but it has been found that the magnetism slowly wastes and in the course of time the machine is worthless unless the field be remagnetized.

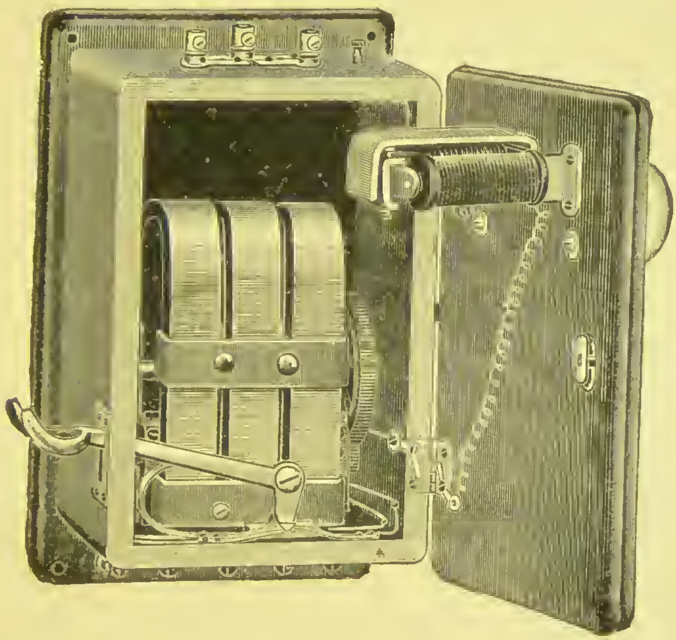

FIG. 47.

The magnet is usually of U shape, and in many cases several are placed side by side forming a *compound magnet* as seen in Figs. 46 and 47. Those machines which have the armature placed between the poles of the magnet, have the latter so shaped as to conform to the periphery of the armature. In another style of this machine the armature is placed at the side of the poles, and in this case the poles are plain surfaces.

The better class of these machines have the poles tipped with pieces of soft iron.

It does not matter whether the armature revolves within the field, or whether the field revolves about the armature for the production of the current, but it is usually customary to fix the field in its position because of its greater weight and bulk. When the field is the stationary part the general type is of U shape with the ends enclosing the armature.

The armature of the magneto is usually an iron core having a longitudinal slot in which the wire is wound. The core is of soft iron and is mounted so as to rotate between the pole pieces of the field magnets. The more closely it is fitted between the pole pieces, the more efficient will be the machine because of the better magnetic circuit.

The winding of the armature core in the magnetos of to-day, since they are used for light work, is quite simple. It is usually of the Siemens or shuttle type. Two deep slots are cut its entire length at diametrically opposite positions. These are wound with insulated copper wire, and the two ends are connected to separate rings or to the segments of a two-part commutator, according to the character of the current that is to be produced by the machine. If the ends are attached to separate rings on the shaft, the current taken from these will be of the same character as that which flows through the coil during its entire revolution, and will change from positive to negative in one revolution as the two poles are passed. If, however, the ends of the wire are attached to two pieces of metal placed diametrically

opposite upon the shaft and insulated from one another, then the current taken off by the brushes will be direct but interrupted because of the small number of coils. If more coils are used the current will not be interrupted, but will become pulsating with smaller waves as the number of segments is increased.

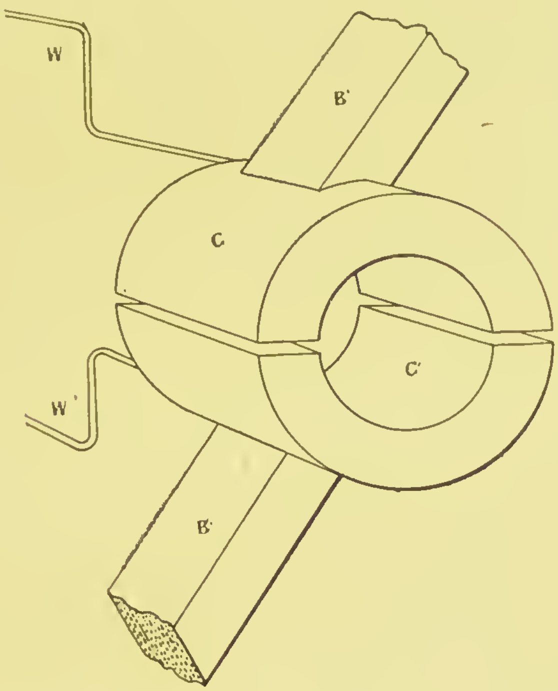

FIG. 48.

The *Commutator* is that part of the magneto by which the current generated in the armature, is conducted to the external circuit. If an alternating current is desired, the two wires just referred to are attached to separate rings which surround the spindle at one end and against which brushes are in light contact; but if a pulsating current be desired the two wire terminals of the armature are fastened to two metal segments

which about half way surround the spindle, as shown in Fig. 48, and against which brushes bear. Where the rings are used each end of the wire of the shuttle is always connected with the same wire of the external circuit, but where the commutator is used, with every half revolution of the shuttle armature there is a reversal in the connections with the external circuit which occurring at the same moment that the current reverses its direction, produces a direct current in the wires leading from the armature.

By the use of rings an alternating current is produced in the following manner. If we suppose, for the sake of clearness, that a single wire is passed in a circle between the poles of a magnet as an armature would revolve, when it approaches the positive pole, current will flow through the wire in a given direction, and as it approaches and passes the negative pole the electric current will reverse its direction. So it is with the magneto with rings. As the coils on the opposite sides of the core pass the two poles of the magnet, a current is caused to flow in a given direction through the wire and as, during the course of a revolution of the armature, the coils approach and pass the opposite magnetic poles, the direction of the current in the wire is reversed.

When, instead of rings, the commutator is employed, the reversal of direction of current does not occur, but in its stead we have a flow of current in one direction but of pulsating character. As each coil on either side of the shuttle passes the poles, current flows in a given direction. As the coils approach the point midway between the poles of the magnet and the electric current

has decreased to zero and is about to change its direction, the segment on the commutator slides under the brush which conducts current of the polarity which its coil is receiving. In other words, during the course of a revolution of the armature, while one side is sending off a positive current, it is, by means of the commutator and brush, connected with the positive wire, and when the same coil has had its current reversed during the other half of the revolution, it is automatically put in connection with the negative wire. And so the movement keeps up. During the time that the coil is nearest the pole the curve is highest and it drops to zero when the coil reaches the point midway between the two poles of the magnet.

THE ELECTRO-DYNAMO.

The distinguishing feature between the magneto and the dynamo lies in the field. The field of the magneto is made up of one or more permanent magnets, whereas the field of the dynamo is made up of electromagnets. While the discovery of Faraday is the foundation of dynamo-electricity, it only became of commercial value by the substitution of electromagnets for the permanent magnets of the field. This discovery was almost simultaneously made by Farmer, Varley, and Siemens in 1866. The magnetism of a permanent magnet is necessarily limited, while that of the electromagnet is limited only by the mechanical problems of heavy machinery. The electrical energy generated by a dynamo of a given size and weight is much greater than that developed by the best gas or steam engine of like

proportions. This is due to the fact that an electro-magnet, so small and simple in itself comparatively, and yet capable of so much power, is the central organ of the modern dynamo. The output of the dynamo is

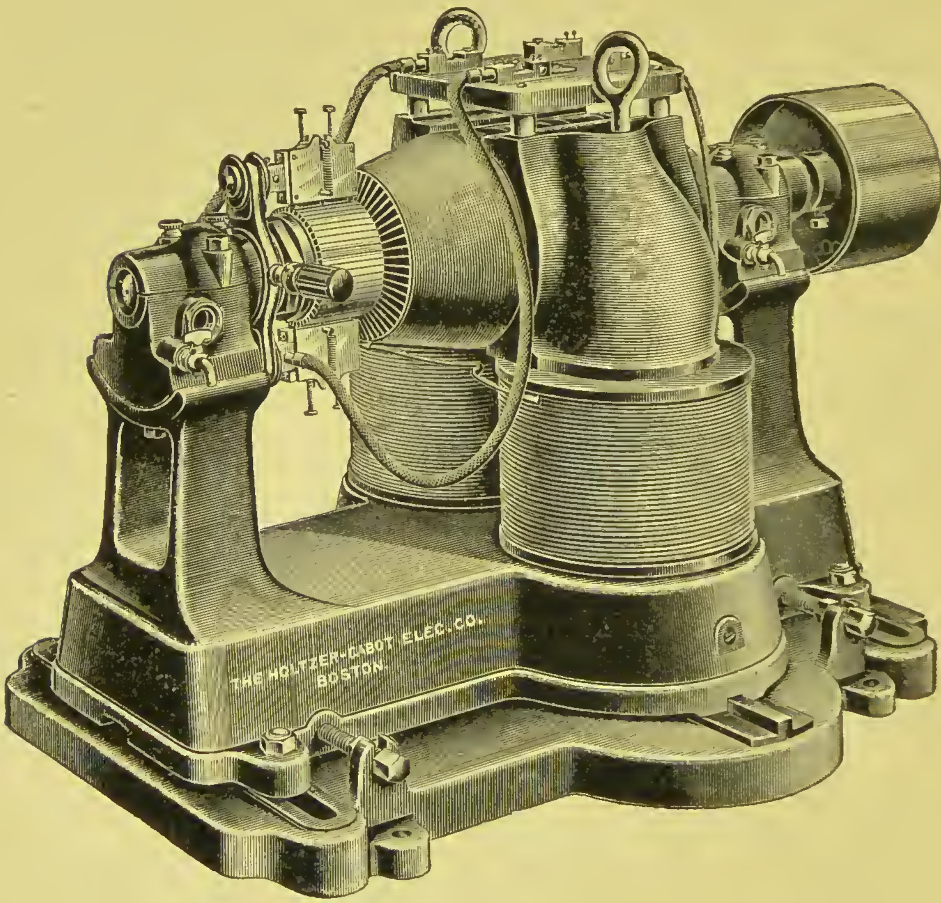

FIG. 49.—TWO POLE DYNAMO.

dependent upon the rapidity with which the moving part cuts the lines of force, and herein lies a feature of the greatest importance. The motion of the moving part is rotary instead of reciprocating, and larger and heavier masses may be put in rotary motion than would be allowable with reciprocal movements. When we con-

sider the large output of energy for the mass and the possibilities of rotary motion of the moving parts, the wonderful performances of the dynamo can be understood.

The modern dynamo, like the magneto, consists of three essential parts, the *field*, the *armature*, and the *commutator*, or *rings*. The field is usually the larger and heavier part, and is fixed in its position. This encloses a smaller organ which revolves, called the arma-

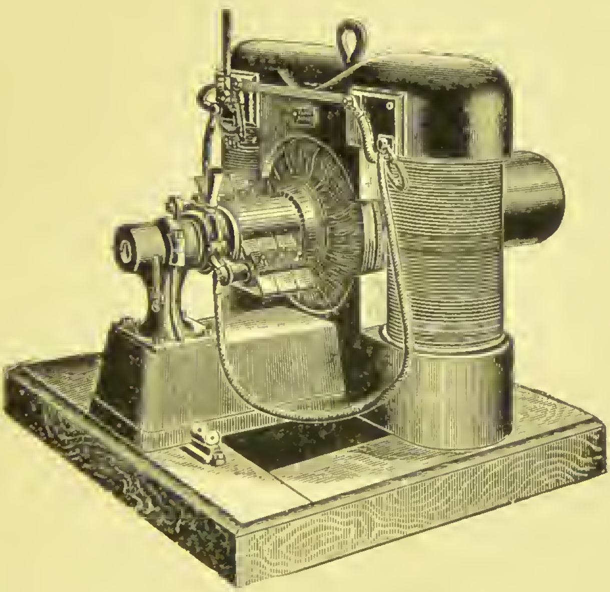

FIG. 50.—TWO POLE DYNAMO.

ture. Upon one end of the armature shaft is an appliance which, in connection with the brushes, is for conducting off the current. This may be in the form of separate plates, one for each coil of wire in the armature, called the commutator, or it may be in the form of two separate bands known as the rings. It is upon the employment of either the commutator or rings that

dynamos are divided into two great classes known as *direct current generators,* and *alternators.*

DIRECT-CURRENT GENERATORS.

The field of the direct-current generators is simply an electromagnet. In the earlier forms of dynamos,

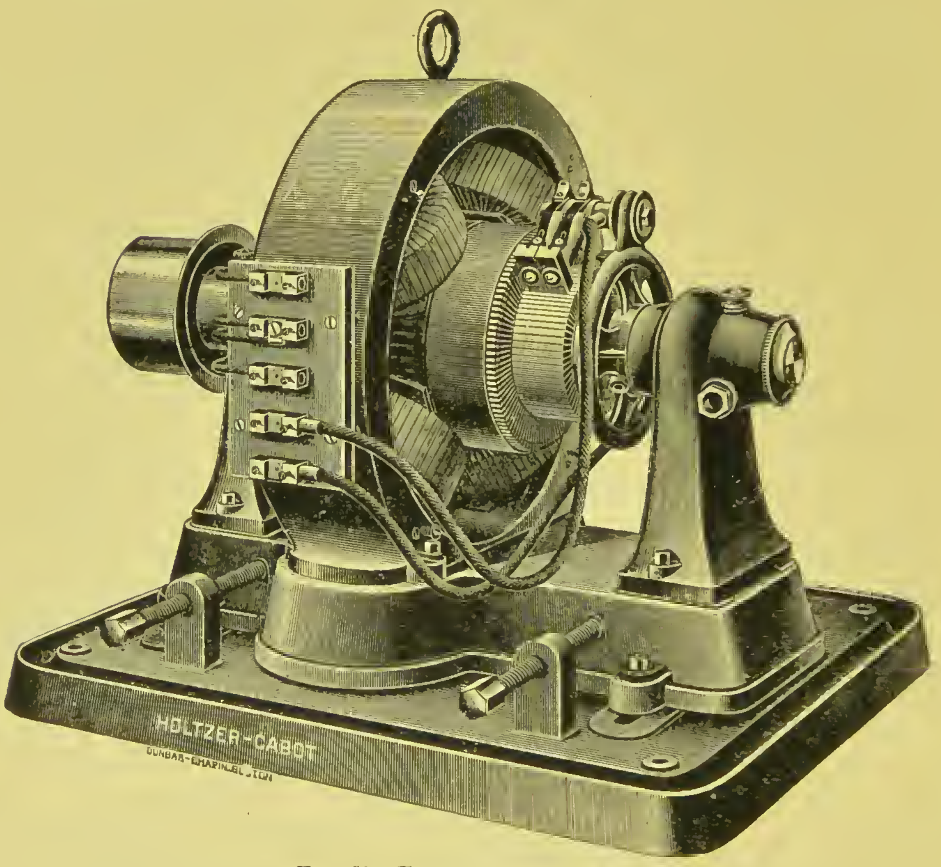

FIG. 51.—FOUR-POLE DYNAMO.

and at this day in the smaller machines the field is of U shape as shown in Fig. 49. As the dynamo was perfected and as the demands for larger machines increased, the field assumed more or less the form of an enclosing frame until to-day the large dynamos have a field per-

fectly circular in design. If, however, one of these be examined it will be found that it is not one large electromagnet, but it is made up of a number of electromagnets placed side by side so as to give the circular appearance of the field. The first step in this direction was the use of two U-shaped electromagnets facing one another with the poles at the point of junction as shown in Fig. 50. Such a field has but two poles. Soon, however, the magnets were separated a short distance which made four poles instead of two, as shown in Fig. 51.

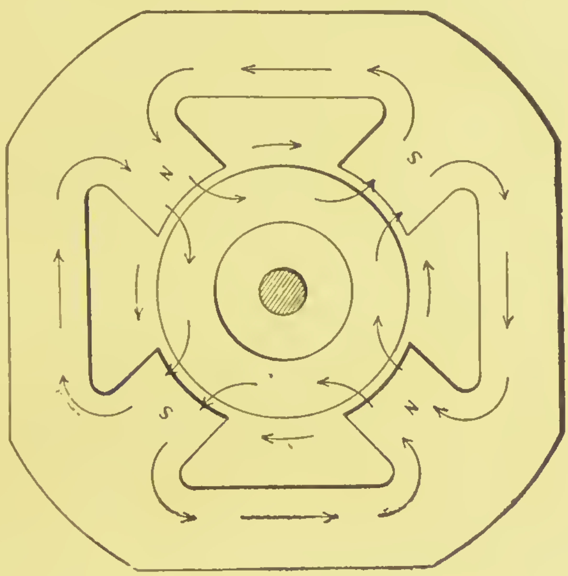

FIG. 52.—DIAGRAM OF MAGNETIC CIRCUITS IN A QUADRI-POLAR DYNAMO.

These poles were properly shaped and placed at such points as to be equally distant from one another. This was followed by enlargement of the circle and the insertion of more electromagnets, but always in pairs, until to-day the field of the largest dynamos has the appearance of a complete ring with its many poles pointing towards the center.

There appeared to be a limit to the size at which bipolar dynamos were proportionately efficient, so that for mechanical considerations the multi-polar type of dynamos came into use. As the subject of dynamo construction was further studied, it was found that a field in the form of a solid iron ring was of great advantage. It not only simplified the construction but offered a better magnetic path.

There will always be found an even number of magnets in the muti-polar machines. These are wound so as to be of alternately positive and negative polarity in

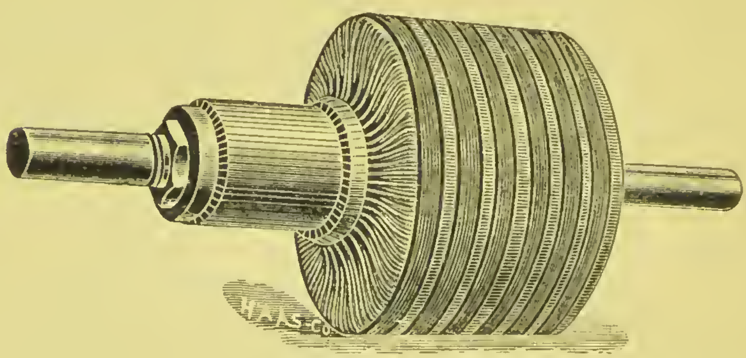

FIG. 53.—ARMATURE.

counting around the circle, and, except in especially constructed machines, the number of brushes to take the current from the commutator is equal to the number of poles of the machine.

It may seem strange that a large iron ring with a dozen or more inwardly pointing poles may have every alternate one of opposite polarity; but this can be understood if we bear in mind that the polarity of a magnet is strongest at the poles, and that there is a neutral point half way between the two poles. The neutral point is

represented by the circumferential ring which joins the several magnets. This ring simply acts as a path for magnetic flux. A positive pole is joined on either side to a negative pole, and if we suppose the magnetic flux to be from the positive to the negative pole, the path divides at the circumference, half going in either direction. This is diagrammatically shown in Fig. 52.

As a matter of fact, the field of a multi-polar machine is made up of a number of electromagnets which are attached to and use a common yoke which is represented by the heavy circumferential casting.

The Armature is the revolving organ of the dynamo. There are a few exceptions, however, in which the field revolves or in which both the armature and the field are stationary and the magnetic connection between the two revolves, known as inductor dynamos, but the form most frequently met with is that in which the armature revolves.

The armature occupies the space between the pole pieces and is carefully balanced so as to insure smooth running. The efficiency of the dynamo depends largely upon the close adjustment of the armature between the pole pieces; hence we find the circumference of the armature perfectly true as it revolves, and the inner surfaces of the pole pieces smoothly dressed and closely embracing the armature. Only sufficient space is allowed between the pole pieces and the armature to insure free rotation of the latter.

Armatures are divided into two general classes according to the construction of the core, the *drum* armature of Siemens and the *ring* armature of Gramme. The

iron of which the core is made is a much better conductor of lines of force than air, and for that reason it is used to fill in the space between the poles. It may be in the form of a solid drum or it may be as a ring or cylinder, and it is upon this point that armatures are divided into the above two classes.

The first drum armatures were composed of a solid piece of iron, but it was found that these cores would unduly heat from the formation of electric currents within them, called Foucault or eddy currents, which were both troublesome and wasteful. The fault, however, was soon overcome by building up the drum of many pieces of iron. The drum cores of to-day are constructed by placing upon the armature shaft a pile of sheet iron discs equal to the length of the armature core. This is further improved by separating the discs one from the other by a thin layer of paper.

The first drum cores were wired by winding the wire upon the surface, called *surface winding*, but for mechanical reasons as well as electrical, it was found better to mill out the discs in longitudinal grooves and imbed the wires in the grooves. By the latter method there is a better means for driving the wires, the teeth of the discs may be brought closer to the pole pieces with safety than wire covered surfaces, the wires are protected, and the drag comes upon the teeth of the core instead of upon the wires.

The ring, or Gramme armature, differs from the drum armature in two respects, the form of the iron core, and the method of wiring. As we have just seen, the drum armature is a solid mass of iron, whereas the

ring armature, as its name indicates, is in the form of an iron ring. Since the cross-section of the iron must be sufficient to carry the lines of force, it is evident that such a core must be of larger diameter than a drum core. It is for this reason that we find the variations in the proportionate bulk of the field and the armature. Dynamos of the same type and the same capacity have quite a different appearance, depending upon the style of armature. Those using the drum armature have the appearance of being quite compact, while those which use the ring armature increase in proportions according to the diameter of the ring.

In the smaller machines, the ring is made up of a bundle of soft iron wires for the purpose of avoiding eddy currents and in the best armatures these wires are heavily varnished to insure less metallic contact with one another. When round wires are employed for this purpose, the cross-section of the ring is one-fourth larger than a solid ring of the same cross section of metal. This may be overcome by using square wire as we find in some instances. The larger cores for ring armatures however, are made up in a manner resembling the drum armature. Thin washers of sheet iron are assembled till the proper thickness has been obtained. These rings are separated from one another by a layer of paper. They are then clamped together and mounted upon a spider-shaped center.

The ring armature is wound in a different manner from that employed in drum winding. In the drum armature, the wires are wound upon or in the periphery of the drum, being carried longitudinally around it

much like twine is wound on a ball, whereas, the ring armature is wound in a manner resembling the binding of the tire to the felly of a wheel. The conducting wire is wound around the bundle of iron wires constituting the core in a manner as if to hold them together. In the winding process the shuttle holding the wire is carried over on the outside and is returned on the inside.

Each of the foregoing armatures has its advantages and disadvantages. The drum armature requires less wire, is free from false inductions, and has less cross-magnetic tendency. Its disadvantages are, greater difficulty of construction, danger of short circuiting due to overwrapping of end conductors, the difficulty of ventilation, and the difficulty of repair.

The ring armature possesses the advantages of simple and easy construction. The coils being wound around the ring are not displaced by centrifugal force. There is no limitation to the diameter of a ring armature, and as the diameter increases the rotary speed may be decreased. A great advantage found in the ring armature is its open construction which permits of good ventilation for keeping down the heat. Another feature is the ease of repair; a defective coil may be replaced without disturbing the others.

The disadvantages of the ring armature are the return wires which add weight and expense without increasing the efficiency.

The design of the armature has much to do with the speed at which it revolves. Since the drum armature is as a rule of less diameter than the ring armature, it is apparent that in order that its wires cut the same

number of lines of force, the number of revolutions must be greater than where the wires are on the periphery of a larger circle. Consequently the speed of the smaller armature must be inversely proportionate to its circumference, and it must revolve at a much higher rate than a larger armature.

The commutator is the third essential part of the dynamo. This, in conjunction with the brushes, is employed for commuting and carrying off the current to the main. If it were not for this device the direction of the current would be entirely reversed with each

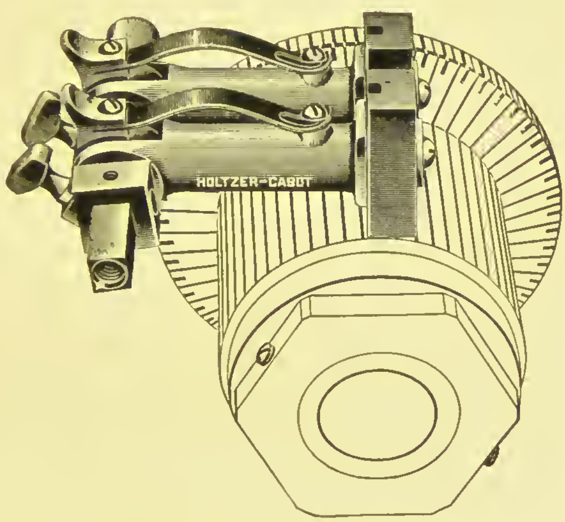

FIG. 54.—THE COMMUTATOR.

revolution of the armature. As it is, however, by means of the commutator and its relation to the brushes, the current of each coil is carried off while it is in the same and proper direction. Those dynamos which have no means for commutation but whose currents are taken off by brushes bearing upon *collecting rings,* furnish cur-

rents which form a distinct class of generators called *alternators.*

The commutator as shown in Fig. 54, is made up of a number of copper ribs which, while electrically insulated from one another are firmly bound together in the form of a barrel. Each rib or segment is dovetailed, and when the full number is assembled they are separately insulated by layers of mica. Cone-shaped mica washers are placed at the ends, and bell-shaped metal caps which fit upon the mica washers are screwed so tightly together as to firmly bind the whole as one. After being mounted upon the armature shaft, it is turned true and made smooth. At the inner end each segment is slotted so as to receive a wire connecting with a coil or coils of the armature. On account of the amount of wear to which the commutator is subject, the segments are usually deep enough to allow of being dressed a great many times before being worn out.

In the course of the entire revolution of the armature each of its coils is caused to successively pass in front of the north and south pole of the field magnet; and the current generated in every coil has been first positive and then negative, and has been completely reversed. Now it is by means of the commutator and its relation to the brushes, as already referred to in connection with the magneto, that at the moment each armature coil is furnishing its fullest positive or negative current it passes under the positive or negative brush and is put in direct connection with the mains to which it delivers its charge. In the small machines with an armature of the shuttle type, as a coil passes a pole, the

current directed to each brush rises and falls to the extent of being almost an interrupted current; whereas, in the larger machines, the larger number of coils successively passing under the brush and delivering their current at its fullest strength, produces a current that is practically continuous. It is for this reason that these machines are frequently called *continuous-current* dynamos. The smoothness of a dynamo-current depends upon the number of coils in the armature. Consequently we find those intended for incandescent lighting and the like to have a large number of coils, and, since each coil is connected with a bar in the commutator, we will find a commutator with the number of bars equal to the coils of the armature.

The current is taken from the commutator by means of brushes also shown in Fig. 54. These are intended to bear upon the commutator just heavy enough to make electrical connection, but not so heavily as to cause destructive wear. It is also important that the contact surface be large enough to carry the current without heating. For this purpose a brush made up of many laminations of copper leaf is very satisfactory. This is not only flexible, but each leaf makes a distinct contact. This form of brush may be further improved by sawing slots longitudinally through half the length of the brush. A brush made of woven wire possesses advantages of flexibility and many points of contact. Carbon is also largely used for brushes and has points of advantage over metal brushes. It does not wear the commutator as do metal brushes, and may be used where the direction of the armature is reversed. When lam-

inated brushes are used, the angle at which they bear upon the commutator endangers catching the brush upon reversing the armature. When carbon brushes are used, however, they may be mounted at an angle, or they may be made to bear directly end on. These brushes operate equally well with the armature revolving in either direction. They are mounted in a spring-operated holder which is insulated from the framework of the machine. If the brushes are of copper, they are frequently fixed so as to bear lightly upon the commutator, and their elasticity is depended upon for keeping the contact. When carbon is used, however, it is necessary to keep it flexibly in contact with the commutator which is done by means of a small spring, the tension of which is regulated by a thumb-screw.

THE WINDING OF THE DYNAMO.

The purpose for which a dynamo is to be employed determines the method of winding. There are three principal methods, the series, the shunt, and the compound.

A series-wound dynamo is one in which one of the terminals of the field is connected with one of the brushes so that a current must flow through the field and the armature in series. This is shown in Fig. 55.

In this method of winding the current traverses a single route of low resistance, first through the armature coils, then through the field, and then through the external circuit. All the current output of the machine must be carried through the armature and field in succession, consequently the wire with which these are

wound must be large enough in cross-section to carry the current without heating.

The effect of connecting the armature in series with the field is to produce a current which varies inversely as the resistance in the external circuit. Any increase in the resistance of the external circuit tends to decrease the flow of current through the field and armature, with the result that the electromotive force is lowered. In order to keep the voltage of the series machines at a uniform pressure, it is customary to shift the position

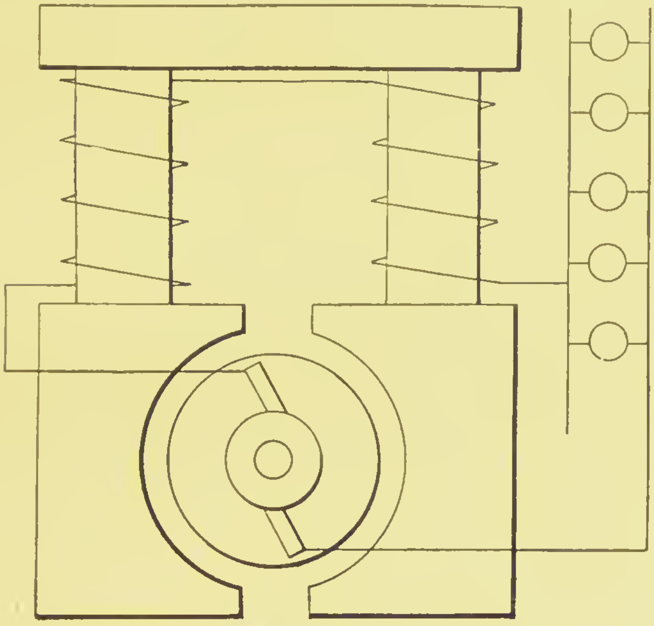

FIG. 55.—SERIES-WOUND DYNAMO.

of the brushes, either automatically or by hand. The brushes are mounted upon an annular bearing outside of the commutator in such a manner that they may be easily moved in either direction as the work put upon the machine demands.

The series-wound dynamo is especially fitted for arc-lighting. Each lamp requires a steady current in amperes, and the pressure necessary for preserving the flow of current across the break must be steadily maintained to insure a good light. The current used in arc lights varies from five to fifteen amperes according to the kind of lamp and the purpose for which it is used. Those used for street lighting usually operate with about nine amperes. Any variation in the current produces an unsteadiness which is quickly noticeable. The pressure required to maintain an arc of nine amperes from carbon to carbon is about forty-five volts. In the operation of an arc-light plant there is a continual variation in the number of arc lights operated by the dynamo. The work required of the dynamo is therefore one which will vary its voltage according to the number of arcs being sustained. Since each lamp requires forty-five volts to operate it, when fifty such lamps are operated by a dynamo the voltage must be 2,250; and yet through all this range of voltage the dynamo must maintain nine amperes. When the series of arc lights has been established, but a slight variation comparatively is caused by the extinction of one, two, or three lamps. This variation in the required voltage is easily accomplished by shifting the position of the brushes, which, as referred to before, may be accomplished automatically or by hand.

The shunt-wound dynamo differs from the series-wound in that the circuit of the armature and field are in parallel as shown in Fig. 56.

The effect of this method of winding is to magnetize

the field independently of the current flowing through the main circuit. The field is usually wound with fine wire so that its resistance is very high, and consequently but a very small proportion of current is shunted through it. The current employed in magnetizing the field of the shunt machine varies from two to twenty per cent. of the whole current. However small the proportionate amount of current employed for magnetizing

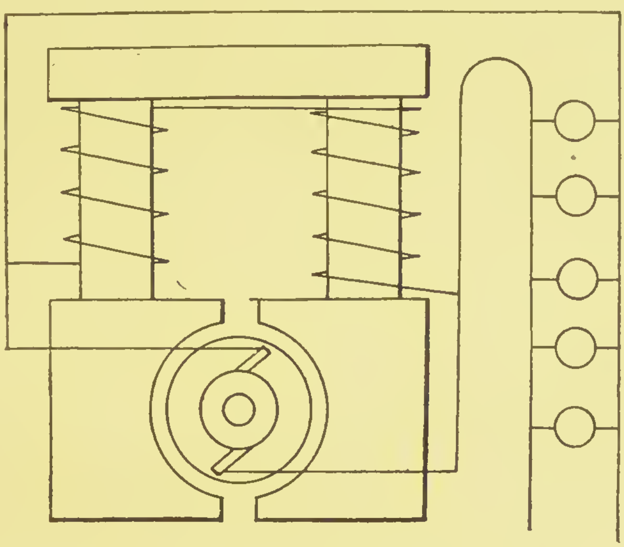

FIG. 56.—SHUNT-WOUND DYNAMO.

the field may be, it has high magnetizing power because of its many turns. The wire carrying the external circuit is large as compared with the wire of the field.

The effect of shunt winding in dynamos is to automatically maintain, within certain limits, an output proportionate to the load put upon it. When the current leaves the positive brush it divides into two paths; one travels around the field of the dynamo and the other through the external circuit. When the current meets

with high resistance in the external circuit it is dammed up, so to speak, in the main, causing an increased flow of current through the shunt wire of the fields. This is but momentary, for the extra current which becomes thus shunted through the field, increases the magnetism of the field sufficiently to overcome the high resistance of the main line. In this way a balance is quickly established. The wire of the field being always of the same length and size, its resistance remains the same but its magnetism is varied by the strength of current shunted through it. The variation of current in the field is somewhat proportionate to the resistance in the main line, and the effect is just enough to meet the requirements in the external circuit.

The shunt-wound dynamo furnishes a current which has a wide range in amperes, but which varies but little in its pressure. It is just the opposite of the series-wound. It is therefore especially fitted for supplying the current for those purposes which require uniform pressure but varying strength of current, such as incandescent lighting, electroplating and the like.

The compound-wound dynamo is a combination of the series and the shunt winding. This form of generator is constructed on the general lines of the shunt machine and has that appearance. It differs from the shunt, however, in that a few turns of the main wire surround the fields. This winding is diagrammatically shown in Fig. 57.

The field magnets are nearly filled with fine wire each end of which is connected to the brushes. This properly constitutes the shunt as in the shunt machine,

and it would be so were it not for the fact that the main line upon leaving the positive brush, makes a few turns over the shunt winding of the fields before leaving the machine. It will be seen, then, that the magnetism of the field is produced by two different sets of wires, one, the more powerful, a shunt to the main, and the other, the less powerful, which is in series with the main. The effect of this arrangement is that we have a combination of the series and the shunt dynamo, and the current will partake of the nature of both. It will vary

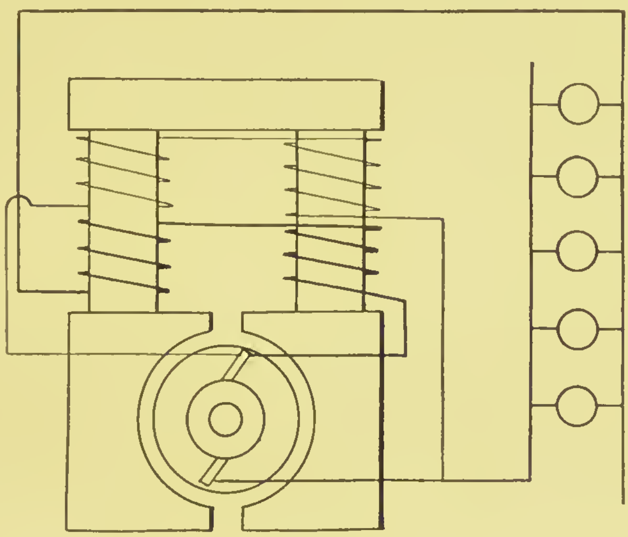

FIG. 57.—COMPOUND-WOUND DYNAMO.

the one way or the other as the proportionate winding in the field is more largely the one or the other. If the field contains more of the shunt circuit than the main, its current will have a comparatively steady pressure with varying strength in amperes. If, however, the field contains more of the main circuit than the shunt, the current will have a more uniform ampere strength, but its voltage will vary.

The compound winding is used in a practical way on dynamos used for incandescent lighting and for street railways. For these purposes there is a constant variation in the load put upon the machine, and to meet this demand there must be a means by which the output of the machine also varies. By compounding the shunt winding with a few turns of the main, the voltage automatically rises and falls with the load. It is possible, however, to carry the compound winding so far that the voltage is increased more rapidly than the increase of load requires, and in such cases it is termed *overcompounding.* But by following established rules, the manufacturer can so proportion the compounding as to exactly meet the requirements, producing a steady current under all variations of load which come within the limits of the machine.

The method of using the current supplied by a series- or shunt-wound machine, and in practice the compound-wound is but a shunt machine compounded for automatic regulation, is similar to the method of winding. There is a striking similarity between the methods of winding dynamos, and the manner of using the current from them. In the series dynamo the current flows through the armature and field in series, and so the current operates in the external circuit by passing from lamp to lamp in series. In the shunt-wound dynamo the current flows through the armature and field in parallel, and, in like manner, it is distributed in the external circuit. All the incandescent lamps and motors operated by it are in parallel across the mains.

ALTERNATORS.

We now come to the second class of dynamos called *alternators*. In the preceding pages, the generators described were those which produced a current whose flow was continuously in one direction, whereas, those which we are now to consider produce one which flows alternately in one direction and then in the opposite.

The alternator depends upon the same principles of magnetic induction for its operation as does the constant-current dynamo, and the current produced by it is of the same nature as that produced by the latter. The marked difference between the two, however, lies in the method of taking the current from the armature, and it is this detail principally, that distinguishes the alternator from the constant-current generator. The difference is not so much in the manner of producing an electric current, but in the manner of conducting the current from the coils to the external circuit. In the constant-current dynamo, the current generated in each coil is taken off under the brush of the same polarity as that of the coil, and as the coil travels around and its polarity is reversed it passes under the brush of opposite polarity. This commuting or rectifying of the current in continuous-current dynamos is accomplished by means of the commutator. In the alternating-current generator, however, the commutator is dispensed with and the current is conducted from the machine just as it is generated in the armature coils. The current is constantly reversing its direction as it passes the alternately positive and negative poles of the field.

Instead of a commutator, the two ends of the armature wire are led out to two metal rings on the shaft. These rings are insulated from the shaft and from one another and are turned perfectly true. They are called the *collecting rings,* and the current is taken from them by means of brushes just as with the commutator on continuous-current machines. It will be noticed that when the commutator is used a wire from each armature coil connects with a corresponding segment of the commutator, and the coils are in parallel with the segments, so to speak; whereas, in the alternator the coils are connected in series with one another, and the two end wires terminate at the rings.

While magnetic induction is the underlying principle and the operating agent in both forms of dynamos, there are structural differences which fit the two classes more advantageously for their respective work. The proportional weight of the armature and its methods of construction in alternators frequently make it mechanically better to keep the armature stationary and to make the field the revolving part. When this is done collecting rings are not necessary, and the alternating current is taken off by direct connection to the terminals of the stationary armature. In another form of alternator both the field and armature are stationary, and a disc with lugs of soft or laminated iron revolves between the two in such a manner as to set up variations in the magnetic flux. This form is called an *inductor dynamo.*

The efficiency of an alternating current depends largely upon the frequency of its alternations, and this is the guiding principle in the construction of alterna-

tors. It is necessary to produce very rapid alternations in the direction of the current, and this is accomplished by using a large number of poles in the field, in order that the number of reversals of direction of the current will be considerable in a single revolution of the armature. In the first alternators used, it was the practice to construct and operate them so as to produce as high as 266 alternations per second. This meant that each coil of the armature must pass 266 coils of the field in one second, which could only be done by obtaining a very high speed of the armature or by having a very large number of poles. There is a limit to the speed that can be safely obtained, and so it became the practice to employ a large number of poles.

As the alternating system became perfected, the frequency of the alternations was reduced one-half. Although this meant a slight increase in the size of the transformer, an essential part of the system, this was offset by more important considerations in the dynamo. It is now the practice to furnish a current of about one hundred and twenty alternations per second. This means that the current changes its direction of flow one hundred and twenty times which is termed the *frequency*. Where the current has reversed its direction and then returns to the first, thus making an entire back and forth movement, it completes a *cycle*, and the above current of one hundred and twenty alternations would make sixty complete cycles in one second.

The advantages of the sixty-cycle over the former one hundred and twenty cycle current are, a reduction in the speed, arc lights operate better, the regu-

lation of pressure is improved, and small motors are more readily controlled.

The alternating dynamo, or the *alternator,* as it is sometimes called, is composed of three essential parts; the *field,* the *armature,* and the *rings* and *brushes.*

The field is generally, but not always, the stationary part. Since the efficiency of alternators is largely due to the frequency of the alternations, the field is made up of a much larger number of poles than constant-current generators. The constant-current dynamos seldom exceed ten or twelve poles, whereas, alternators frequently have three or four times that number. The method of arranging the field magnets in alternators varies more than in the constant-current machines. In the Ferranti, Wilde, and Siemens alternators one-half of the field is placed on one side of the armature, and the other half on the other. The poles point toward one another and, being of opposite polarity, the armature coils cut lines of the strongest magnetic flux. Another generator, of English make, has a stationary armature and a rotating field. The field is one large bobbin in the center, and two heavy castings with twelve claws are fitted upon the ends. These claws bend over towards the middle of the bobbin so that when the two have been fitted on the field bobbin the claws entirely enclose it except for a space of three-quarters of an inch in which the armature coils stand. By this arrangement all the claws of one end are of one polarity, and those of the other are of the opposite polarity. Since the armature coils are in the form of a disc and stand in the three-quarter inch space between the claws, they cannot

be of very great thickness, and the rotating field must have but little end play. The armature coils are thin copper strips but one-third of an inch wide, and are wound in a manner similar to the winding of a ribbon on a spool, except that the form upon which the ribbon is wound is oblong instead of round.

The form of alternator most frequently met with

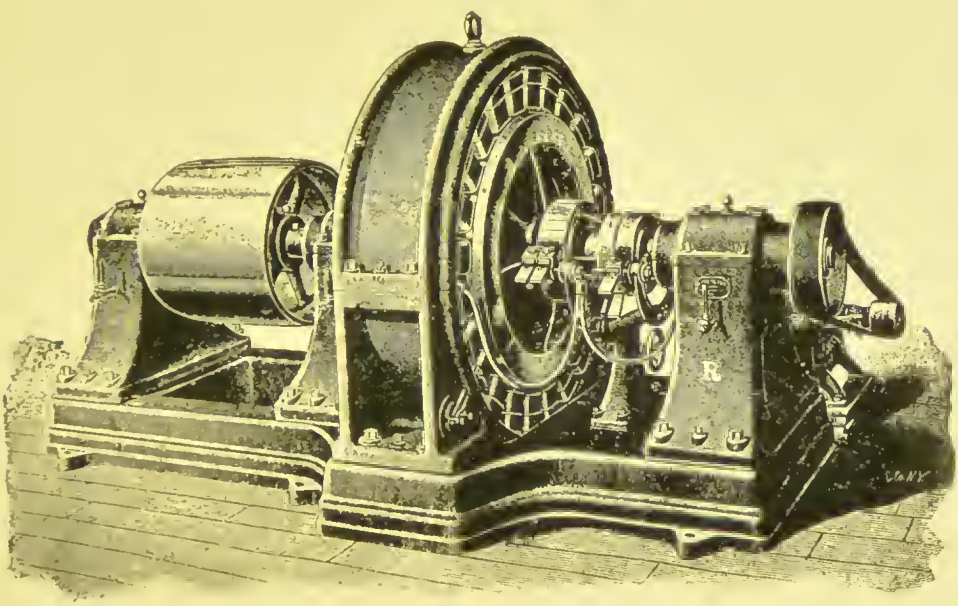

FIG. 58.—MODERN ALTERNATOR.

in this country resembles the constant-current generator in its general outline. The poles are arranged in a similar manner on the inner surface of the circumferential casting. Such an alternator is shown in Fig. 58.

In this illustration it will be noticed that the principal difference from the constant-current generator lies in the large number of bobbins and in the narrow rim of the field casting.

The armature of the alternator also varies more than that of the constant-current dynamo. It may be of the ring, drum, pole, or disc type. The coils may be wound similarly to the constant-current armature, they may be wound on bobbins, or they may be made up of strips of copper ribbon. It depends upon the form of field as to which kind is employed. Where the field is of the constant-current type, the armature also has that appearance. If, however, the field consists of bobbins which are arranged on either side of the armature, the winding of the armature is in bobbins. Or, if, as in the Mordey or in the Ferranti, the field is a pair of crown plates, the armature coils are of copper ribbon wound upon wedge-shaped cores with an insulating layer of tape between them.

The method of winding the armature determines the nature of the core to be used. If the armature is of the continuous-current type the core is constructed in a similar manner, and the rules for avoiding eddy currents are followed as before. The cores are made up of laminated iron, and the only apparent difference is in the number of teeth or grooves in the periphery. In the continuous-current core, if it is grooved, there are as many grooves as there are segments in the commutator; but in the alternator there are only as many as there are poles. The depth of the grooves is inversely proportional to the number of armature coils. In the continuous-current armature they are shallow and contain but a few turns of wire, whereas, in the alternator they are deep and contain a proportionate amount of wire. It is customary to proportion the

depth of the cut and the distance from one another so that the partition of iron is about equal in cross-section to that of the groove.

Since the efficiency of this class of machines depends upon the alternations, the grouping of the winding in such a manner as to make the strongest poles is the principal consideration, and hence the tendency toward winding the coils around projections, or pole pieces of the armature core. This method of armature construction is followed in most single-phase alternators.

The armature of the alternator is wound in such a manner that the alternate poles are of opposite polarity. In passing around the circle, the direction of winding is reversed on every pole, and if the type is a pole armature it will not differ materially from the field. As a matter of fact, the field and armature are so nearly alike that in some alternators of this type it is difficult to determine which is the field and which is the armature.

The armature windings of alternators are either series or parallel series. In the series winding, the two ends of the wire are brought close together in completing the circle, whereas, in the parallel-series winding the circuit is divided into two paths which travel in opposite directions until they meet at a diametrically opposite point. In the series winding the points of highest potential are brought dangerously close together, while in parallel-series winding they are farthest apart. The series winding, however, only requires half the number of turns to generate the same electromotive force as that generated by the parallel-series winding.

The rings of the alternator perform a duty similar to

the commutator of the constant-current dynamo. They provide a means for conducting the current from the armature, but differ from the commutator in that they do not alter the connections so as to change the character of the current. Since in the revolution of the armature, the coils pass field poles whose polarity is alternately opposite, the current produced in the armature will alternate as each pole is passed. By means of the rings and the brushes which bear upon them, the current is led to the external circuit, just as it is generated in the armature coils, and it will alternate in direction as it passes each pole. They are, in fact, the two terminals of the wire with which the armature is wound and should be so considered.

The rings are mounted on the armature shaft, but are electrically insulated from it and from one another. The terminal wires of the armature coils are carried to the rings in the body of the shaft. The rings are made of brass or copper, and are turned true and smooth after being mounted on the shaft.

The brushes employed on the alternator are like those used on the constant-current machines. They may be of copper, copper-gauze, or carbon. Inasmuch as the surface of the ring is continuous and much smoother than the commutator of constant-current dynamos, the wear of both the ring and brush is much less, and sparking is entirely absent.

There are two methods of connecting the armature coils of the alternator. In one the coils are connected one to another in series, and the other is the parallel in which the two terminals of each coil connect to two

common wires which encircle the armature. The two terminal wires of the series machine terminate at the two collective rings, and in the same manner the two common wires of the parallel machine also terminate. The series connected produces a current of high voltage, because the E. M. F. of each coil is added to that of the others, whereas in the parallel connected the voltage is only that of a single coil, but the current strength is proportionately increased. Let us suppose that each coil of a twelve-coil armature produces ten volts and ten amperes. If these are connected in series the current would have a pressure of 120 volts and ten amperes, but if connected in parallel the current would have a pressure of but ten volts and the ampere strength would be 120.

It is therefore possible to connect the coils of the armature, just as cells may be connected, so as to give any desired capacity of current to meet the requirements of the case. If a current of high pressure is desired the series method is used, and if a heavy current of low pressure, the parallel method is indicated, and any output between the two may be had by a combination of the series and parallel methods.

An alternating current is not suitable for magnetizing the field, hence it is necessary in alternators to generate a direct current for this purpose, either by a separate machine or by commuting a part of the alternating current. For the purpose of regulation both methods are sometimes employed in the same machine. Fig. 58 shows an alternator of this kind. A direct current for energizing the field is taken from the armature by means of the commutator near the armature, the

alternating current being taken off at the two rings beyond the commutator. About one and five-tenths per cent. of the power of the generator is required for magnetizing the field. All alternators are for this reason divided into three general classes; namely:

1. Separately excited, or those which secure their field excitation through an independent dynamo. This is sometimes operated by a belt from the armature shaft, and in some cases a continuous-current dynamo is mounted on the same shaft with the alternator.

2. Self-excited, or those in which a part of the armature current is commuted and sent through the fields direct. This form of alternator has a commutator as well as the two rings.

3. Compound-wound, in which there is a combination of the above two. The principal excitation of the field is obtained from a separate dynamo, but for the purpose of better regulation an auxiliary current is taken from its own armature by means of a commutator.

If one alternator be connected in series with another alternator of the same kind, one may be operated as a motor so long as the two are in step. It will not start from a state of rest, however, but requires to be started. It must also operate at an equal speed with the generator, and when doing so is said to be operating *synchronously*. These objections were found when the first alternating currents, which were *uniphase* currents, were being used for power purposes. They, however, led to what is known as *multiphase* currents, and the alter-

nators are now called *diphase, triphase,* and *monocyclic* generators.

The uniphase is but a single current, while in the diphase there are two and in the triphase there are three currents. The uniphase current in its operation of a motor may be compared to an ordinary engine with one cylinder. The engine cannot be started from a state of rest if it is upon a dead center, but requires to be started. In the diphase there are two separate currents, one-quarter of a cycle apart. This has its analogue in the ordinary locomotive. Here there are two cylinders and the pistons being connected to the same shaft ninety degrees apart, both cannot be on a dead center at once. Hence the locomotive can start from any position, and in like manner a motor can start when operated by a diaphase current.

The triphase alternator supplies three separate currents one-third of a cycle apart and possesses features not found in the others. It requires only three wires for its distribution, whereas the diphase requires four when operated to the best advantage.

Recently a fourth system for the distribution of alternating currents has come into favor, called the *monocyclic.* This is primarily a uniphase current with a third wire called the *power wire.* For all purposes of lighting the uniphase current answers the requirements, and is supplied by two wires, but where power is used a third wire is supplied. This wire being comparatively small does not add greatly to the expense.

The method whereby the two currents of the diphase or the three currents of the triphase systems are sent

out precisely one-fourth or one-third of a cycle apart is this: The armature has two or three sets of windings as the case may be, which are successively brought under the field poles at exactly one-fourth of the cycle for the diphase currents and at one-third cycle apart for the triphase current.

THE TRANSFORMER.

The chief commercial value of the alternating current lies in the fact that it can be distributed at long distances from the source of supply at a less cost and at a much less loss of energy than by any other system. The alternating current is usually sent out at high tension because of the fact that loss in the conductor decreases with the rise of tension. The loss is inversely proportionate to the potential. The cost of conductors is a very considerable item in electrical distribution, so that a system requiring small conductors as does the alternating is especially suitable for distributing at long distances.

It is customary to supply the alternating current at a high potential. While the voltage of constant currents is usually in the hundreds, that of the alternating is usually in the thousands. An alternating current of two thousand volts commonly met with is dangerous to life and such a current should not be brought into houses. Moreover the appliances to be operated by the current, such as lamps, motors, etc., do not require high voltage. It then becomes necessary to reduce the voltage to one which can be safely handled. This is done by means of the *transformer*. As a matter of fact, if it

were not for the transformer the alternating current and system would be of very little commercial value.

It is by means of this instrument that the high-tension current can produce a current of low tension and *vice versa.* The main current passes through the transformer, and the induced current for use in the house is of reduced voltage and is conducted to the house on a special set of wires. The wires which carry the current

FIG. 59.—THE TRANSFORMER.

from the power-house are called the *primary* wires, while those which carry the current from the transformer to the house are called the *scondary.*

The transformer is a very simple instrument in its construction and action. It is simply an inverted induction coil and consists essentially of a soft iron core upon one end of which are wound the coils of the pri-

mary and upon the other end of which are wound the coils of the secondary. If two spools of thread be slipped on a lead pencil we would have an illustration of the transformer. The pencil represents the iron core and the spools of thread represent the primary and secondary coils. Such a transformer is diagrammatically shown in Fig. 60, in which P represents the primary and S the secondary wiring.

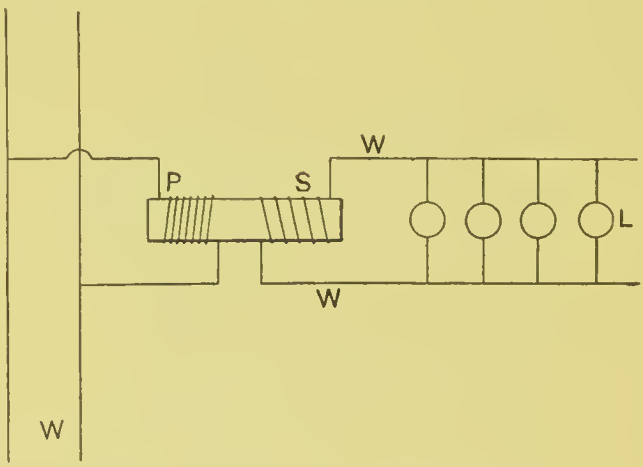

FIG. 60.—DIAGRAMMATIC ILLUSTRATION OF ALTERNATING SYSTEM.

For greater efficiency and economy of space and material the forms of the core and coils are not always like those in the above illustration, but are subject to as many different forms as there are manufacturers. The core is generally, however, bent upon itself so as to form more or less completely a ring or a square.

The operation of the transformer is somewhat complex if followed out in detail. When current flows through the primary in alternate directions, it magnetizes the iron core in opposite directions which in turn induces an alternating electric current in the secondary,

and we have first, an alternating electric current in the primary, second, an alternating magnetism in the core, and third, an alternating current in the secondary. The alternations in the secondary are in the same direction as those of the primary. If we go further into the detail of the operation it would be as follows: When an alternating current flows through the primary it sets up a current having an opposing effect which acts as a choking coil. The iron core becomes magnetized with the alternations of the primary, but in an opposite direction and of such strength that the primary current is not overpowered by the choking effect. The secondary then becomes the seat of an electromotive force by induction from the core with alternations of the same direction and frequency as the primary. The effect of closing the circuit of the secondary through a lamp or motor is to reduce in a backward chain of transformations the choking effect of the counter electromotive force of the primary. This allows more current to flow through. In this manner the transformer becomes automatic in its action and is self-regulating.

The efficiency of the transformer depends upon the rapidity with which the iron core loses its magnetism. The best transformers, therefore, have their cores made up of the softest iron obtainable. The iron is further divided into as many parts as possible by building it up of wires or of thin sheets, the object being to increase the intensity and to reduce to a minimum the heating which takes place in solid cores. This is then carefully insulated from the coils which cover it.

The coils of the transformer are, as stated before,

the primary and the secondary. These are placed as closely upon the iron core and as close together as the insulation will allow. Owing to the great danger if a ground should be established between the primary and the secondary, the insulation of the coils from the iron core and from one another is a matter of the greatest importance and is most carefully made.

The two coils bear a definite and fixed relation to one another. The output in volts and amperes is always proportionate to the windings of the primary and secondary. If the number of turns of the secondary are equal to those of the primary the induced current will be of the same electromotive force provided there is no magnetic leakage. If, however, the coils of the primary are ten times those of the secondary, the electromotive force of the latter will be only one-tenth that of the former. Or, if we reverse the conditions and give the secondary ten times as many turns as the primary, the voltage of the induced current will be ten times that of the primary. While the voltage of the secondary current is thus proportionate to the relative number of turns as compared with the primary, the ampere strength of the secondary current is in an inverse ratio. That is, the fewer the number of turns of the secondary as compared with the primary the higher will be its ampere capacity. The watt output of a transformer of a given number of turns in the primary and secondary will always be uniform if the same strength of current be maintained in the primary. It does not matter how much the relations between the windings of the primary and the secondary be altered, so long as the

total number of turns be retained the watt output of the transformer will be practically uniform. Herein lies a very important feature of the transformer, for by this it is possible to easily secure a current of very high voltage or to obtain one of very heavy ampere strength. The wonderful Tesla effects are due to one arrangement of the coils for high voltage, and the heating of large pieces of metal is due to the opposite arrangement. Where the pressure is raised it is called a *step-up* transformer and where it is lowered it is called a *step-down* transformer.

The commercial use of the transformer is mainly in the distribution of current in small cities or where a large area is to be covered by the distributing wires. For this purpose the primary current is supplied at perhaps two thousand volts' pressure and a step-down transformer is employed which will give a secondary current of about fifty-two or one hundred and four volts' pressure for the consumer's use.

THE MOTOR-DYNAMO.

The motor-dynamo is practically a motor on one side and a generator on the other. It is sometimes necessary to use a current different from that supplied by an electric company. In some cases the only current accessible may be the five-hundred-volt current while the appliances require one hundred and ten volts for their proper operation. This can be met by operating a suitably large motor by the five-hundred-volt current and this motor in turn either by a belt or shaft, operating a dynamo which will generate a current of one hun-

dred and ten volts. If, instead of using the belt or direct connecting shaft the two armatures are wound on the same shaft the transformation of energy will be accomplished most economically. This led to the con-

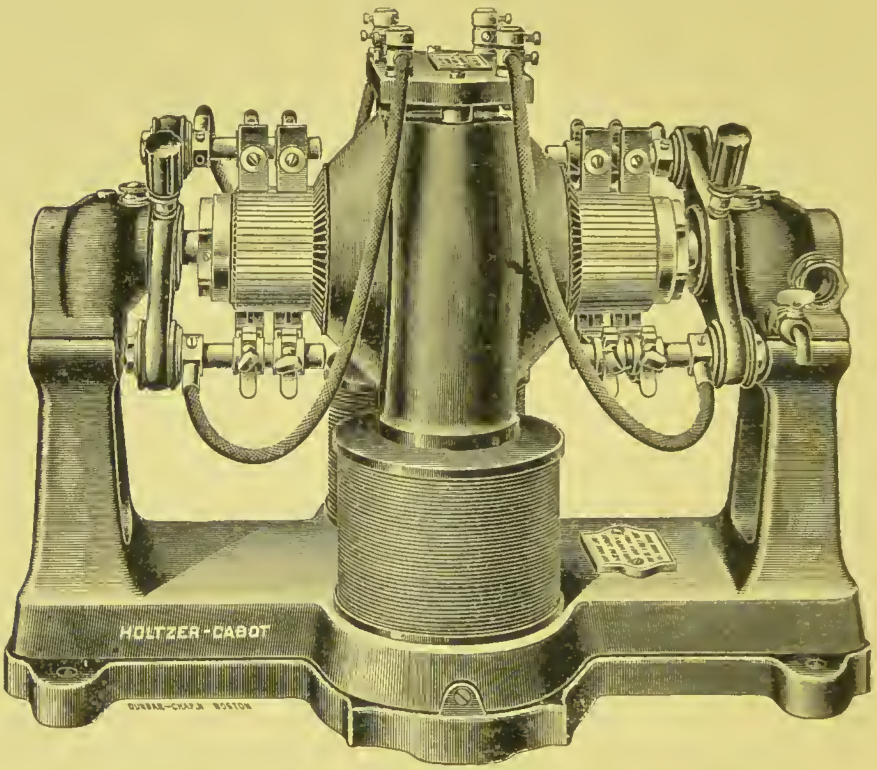

FIG. 61.—MOTOR-DYNAMO.

struction of what is commercially known as the motor-dynamo, one of which is shown in Fig. 61.

The same shaft is used for both windings. On one end the current is received which revolves the armature and from the other end the current which is developed by the outer winding is taken off by means of a commutator for a direct current or by rings for an alternating current.

THE STORAGE BATTERY.

The term *"storage battery"* is applied to a set of cells in which an electric current when passed through them produces such electrolytic changes that, if the external circuit be afterwards closed, these new compounds will return to their original state and in so doing, an electric current will be established. These cells have also been called *secondary* and *accumulators.* They are secondary only in the sense that a primary current must first be used to charge them, and they are accumulators only in the sense that the same kind of energy which has been used in effecting the electrolytic changes is given off after closing the external circuit. Strictly speaking, electricity is not stored, nor does it accumulate in them, but certain unstable electrolytic changes are produced, which return to their original combinations when the proper conditions are afforded, as by closing the external circuit, and in so doing an electric current is generated. Electric energy was necessary to break up the original compounds, and a current of electricity is developed when the compounds return. It is the second display of electric energy that is peculiar to and is the valuable feature of the storage battery.

The first observations which led up to the discovery of the storage battery were made by Gautherot, a French scientist in 1801. He found that after platinum or silver wires had been used to decompose a saline solution, an electric current would be given off even after the battery had been disconnected. Ritter, two years later, made the same observation with gold, copper, brass,

and iron electrodes, and while the underlying principle of the storage battery was discovered at this time, the current was so feeble that the phenomenon did not attract much attention till 1860 when Gaston Planté made use of lead plates. The Planté battery was an important step and when in 1880 Metzger, Fauré, and Brush, independently of one another applied the active material mechanically instead of by the long process of Planté in "forming" the plates, the commercial importance of the storage battery was realized.

The Planté battery consisted of two sheets of lead rolled up in compact form with an insulating layer of thick cloth between them. A solution of dilute sulphuric acid was used as the electrolyte. In order to make this cell useful it was necessary to pass an electric current through the cell and then discharge it a number of times. Repeated action of this kind produced a porous or spongy condition of the surface of the plates which made the electrolytic changes of much greater value and intensity than could otherwise be obtained. This process was known as "forming" the cell.

The chemical reactions which take place are these: During the charging, peroxide of lead, PbO_2, forms on the plate to which the positive wire is connected, and hydrogen on the plate to which the negative wire is connected. Upon discharging the plates, a series of chemical changes follow. The peroxide becomes a monoxide PbO, and finally by the action of the acid, a sulphate of lead, $PbSO_4$. A thin film of the sulphate covers both plates after the first discharge. The plates

are then charged in the reverse order and the sulphate on the positive plate becomes peroxide of lead and that on the negative plate is reduced by the hydrogen into spongy lead. With each charge and discharge, the layers of peroxide and spongy lead thicken, and the efficiency of the cell increases to a degree which is in a measure self-limiting.

When the cell is put into active use the same chemical reactions that were operative during the formation of the plates, continue. If the operation of the storage cell be studied, it will be seen that it is dependent upon chemical action, and differs from the primary in two particulars. The primary cell is so constructed, chemically, that a current flows upon closing the circuit and continues at the expense of one of the elements, whereas, in the storage cell the action is dependent upon the salt of one of the elements. The primary cell is made up of elements which are ready to form new compounds upon closing the circuit, whereas, the storage cell requires its active surfaces to be put into a condition ready for chemical change by a previous electrolytic process.

The process of forming the Planté cell was long and tedious. It required a period of rest as well as one of active charging and discharging; and it was, moreover, necessary to repeat this many times, until a sufficient thickness of the prepared surface had been obtained. This was the principal objection to the Planté cell, and it was twenty years before it was found that the salts which were so slow in forming by the cell's own electrolytic action could be cheaply obtained in the form of minium, which, by a single reduction would be con-

verted into the peroxide on the one plate, and into spongy lead on the other. To C. A. Faure, another French electrician, belongs the credit of this improvement. This cell was made by coating each plate with a paste of red lead, Pb_3O_4, mixed with sulphuric acid. When an electric current is passed through it, that on the positive plate is rapidly reduced to peroxide and that on the negative to spongy lead. It will thus be seen that the difference between the Planté and the Faure cell lies in the method of obtaining the peroxide and spongy lead. The Planté process was by the conversion of metallic lead into a peroxide and spongy lead, and the Faure process was by reducing a higher oxide to a lower, which is a comparatively easy and rapid process.

The Faure cell had a serious fault in that the salt was not closely adherent to the plate and in the course of time it would fall off, and, collecting at the bottom of the cell would cause short-circuiting of the plates, when the cell's action would cease. This fault was soon overcome by constructing the lead plates in the form of a grid so as to mechanically hold the salt in its place. The openings of the positive plate were filled with minium and those of the negative plate with litharge, PbO. The minium, Pb_3O_4, of the positive plate is then reduced to the peroxide by electrolysis which takes about twenty-four hours' time, and the litharge of the negative plate is reduced to spongy lead which requires about six days. When this is done at the factory special appliances are used for this purpose.

The cell when fully charged has two well-marked

plates. The peroxide of lead of the positive plate is brownish in color, and the porous lead of the negative is slate colored. When the cell is discharged both plates assume the same appearance, for the reason that the chemical action during the discharge has been to reduce the peroxide of the positive and the spongy lead of the negative to the same substance. The peroxide is reduced to a monoxide and the spongy lead has been oxidized. An atom of oxygen has left the peroxide and an atom of oxygen has been added to the spongy lead. Upon recharging, the opposite chain of reductions takes place, an atom of oxygen is taken from the negative plate which reduces that to spongy lead, and an atom of oxygen is added to the monoxide of the positive, making that a peroxide.

When the circuit is closed and the cell is at work there is more or less activity in the lead salts, and unless these are firmly anchored they are liable to misplacement. Herein is the principal difference to be found in commercial batteries, the objects to be attained being the holding of the salts in contact with the plate sufficiently firm to withstand the most violent electric discharge and mechanical usage. Some employ a plate perforated with dove-tailed holes which securely anchor the paste. Others make up the plates of alternate strips of lead and the paste. In fact, there are as many methods of making the plates as there are manufacturers of storage cells.

The completed cell consists of an odd number of plates. Beginning with a negative, they are arranged alternately positive and negative, and stopping with a

negative. The plates usually have a projecting lug, and are so arranged in the cell that all the positive lugs are on the one side and the negatives are on the other. The positives are then connected to a common strip which forms the positive terminal and the negatives to another which forms the negative terminal.

The greatest care is exercised in preventing lateral contact between the plates. For this purpose vulcanite rods, or any substance which will withstand the action of the acid and which is not a conductor of electricity may be used. In portable batteries perforated rubber grids, asbestos, or cellulose partitions are used.

If the battery is to be stationary, a glass jar is the best vessel for containing the plates, as it admits of a free inspection of the condition of the cell. If ridges project upwardly from the bottom of the jar, upon which the plates can rest, there will be little danger of short-circuiting within the cell by an accumulation of the paste at the bottom. When the cell is to be used for portable purposes, the jar is made of vulcanite and the top is entirely closed save for a small opening for vent.

The electrolyte used in the storage cell is a dilute solution of sulphuric acid in the proportion of one of acid to four of water. This has a specific gravity of 1.14 or 19 degrees Baumé. While a solution with a larger per cent. of sulphuric acid would be a better conductor, it increases the tendency to the formation of a sulphate upon the surface of the plates which is not only a non-conductor, but decreases the area of active surface. The strength of the solution varies considerably during

the working of the cell, so much so that if an acidometer be used, the amount of charge can be told thereby. The percentage of acid increases as the cell becomes charged and the reverse when the cell is discharged. The density at the beginning of a charge may be 1.16 but when the cell has been fully charged it may be 1.22, which is equivalent to changing the proportions of acid from one to four, to one to three parts. The range between the two is such that the acidometer may be employed to tell the degree of the electric charge in the cell.

With the increase in the acidity of the solution the internal resistance of the cell decreases. This continues till the proportions are about equal after which an addition of acid increases the resistance. Absolutely pure sulphuric acid is not as good a conductor as a weak solution of the same.

In preparing the acid solution earthenware jars are the best vessels that can be used. Considerable heat is generated by mixing sulphuric acid with water which a glass vessel will not withstand. The acid, one to four of water, should be slowly added to the water, and not the reverse. The mixture should then stand till cool before being put in the cells.

The storage cell produces a working electromotive force of two volts. The average voltage produced by primary cells is a little over one volt, depending upon the character of the cell. At one extreme the Smee cell scarcely exceeds half a volt and at the other the chromic acid and Fuller cells reach as high as two volts, but the average working voltage of the primary

cell is but little more than one volt. We thus see a marked difference between the primary and storage cell in respect to the voltage of the cell.

Another feature of the storage cell is the even pressure which it maintains throughout the discharge. Most primary batteries show a gradual decline from the beginning of their use till consumed, whereas the storage battery maintains a practically uniform pressure throughout the discharge. When the storage cell is freshly charged the pressure may reach 2.25 volts, but this being due to the accumulation of free oxygen on the positive plates and hydrogen on the negative it soon drops to about two volts. These gases are the first to be reduced, and in the course of half an hour the voltage has dropped to its normal working pressure where it remains till the cell is about discharged.

The capacity of a storage cell depends upon the area of positive surface, and this is determined by the number and size of the plates. The capacity is rated in *ampere hours*. A cell of thirty ampere hours is said to give a current of thirty amperes for one hour, or one ampere for thirty hours. This is theoretically what such a cell should do, but in practice it is found that if discharged too rapidly much of the stored energy is not effectively utilized. A thirty-ampere hour cell when discharged at an excessive rate may not yield more than twenty ampere hours. Moreover, a storage cell cannot be discharged at a very high rate with safety, as the rapid chemical action and the evolution of gases tends to loosen the salts from the grid. The rate of discharge should not exceed one-fifth of the cell's capacity. Thus

it will be seen that two important features are involved in using a low rate of discharge; the efficiency of the cell is greatest and it is not endangered thereby.

The capacity of the cell is proportionate to its bulk and weight. The earlier cells of the Planté type supplied about three amperes for each square foot of positive lead surface, but the modern accumulators having pasted plates, have double that capacity. If the capacity be estimated by weight a modern cell will give about four ampere hours for each pound of lead. The grid is composed of metallic lead and this makes up the principal weight of the cell. For special cases the grid can be made quite thin and the efficiency of the cell still retained. Portable batteries are made in this manner, and many of them will give five ampere hours per pound of lead. This refers only to the weight of the metallic lead composing the grid. A complete cell of thirty ampere hours would weigh about thirteen pounds. Of this the plates weigh eight pounds, the solution two pounds, and the containing vessel and the connections about three pounds.

The storage cell can only be charged by a current which flows continually in one direction. The underlying principle of the storage cell is the changes which take place in the lead and lead salts. These changes are produced by electrolysis, and the electrical charge depends upon the depth or quantity of lead salts that have been thus changed. Hence there must not only be a change in the active material, but there must be a quantity of the material changed. This can only be done by a current which flows in one direction, for a re-

versal in the direction of the current would reduce what had been previously built up. An alternating current would produce an electrolytic change at its first impulse, but this would be undone upon reversal of direction. It is for this reason that the alternating current cannot be used for charging storage cells or for any other electrolytic purposes. In order to effect a deep change in the lead and its salts the charging current must flow continually in one direction. Such a one is known as a *constant current* and is found in the Edison system for incandescent lighting, the two hundred and twenty volt power current, the car current and the arc-light current.

The charging current must also be of high enough pressure to overcome the voltage of the cell. Every cell while being charged has its external circuit closed through the charging appliance, whether it be a set of primary cells or a dynamo; and the storage cell would discharge through the charging appliance if the latter had not pressure enough to overcome that of the storage cell as it became charged. The pressure, therefore, at which a storage cell is charged should be at least two and five-tenths volts. The charging current may be of a thousand volts if its ampere strength is not higher than the capacity of the cell. It is for this reason that storage cells may be charged by a few primary cells or by an arc-light current. So long as the charging current is not of too high ampere strength no harm will be done. It is customary to charge at about the same rate as that at which the cell is discharged. The arc-light current is one of from eight to twelve amperes' strength, and

a storage cell of one hundred ampere hours or over can be charged by this current without danger to the cell. Or, a set of smaller cells whose ampere hours are a hundred or more, may be charged by the same current if they are connected in parallel. In this way the ampere strength of the charging current is divided between the cells so that each cell only receives a part of the charging current.

In making the connections for charging, the positive terminal of the charging current is to be attached to the positive plate of the cell and the negative terminal to the negative plate. The positive plate, if not marked, can be told by its dark color and the negative plate by its light slate color. The polarity of the charging current can be told by the pole detector. Another and a very convenient method is to dip the terminals, if not carrying a dangerous current, in a glass of water. Bubbles of gas will form on the negative terminal. If the charging current is weak the water may be acidulated when the effect will be more pronounced. A strip of moistened litmus paper can also be used for testing. This will give a red color at the positive terminal and a blue color at the negative terminal.

The time required to charge a storage battery depends upon the strength of the current and the size of the cell. A cell of twenty-five ampere hours would require about nine hours to charge at a safe rate of about three amperes, and a current of about one and one-half ampere strength would require twice that length of time.

There are three indications as to when the battery is fully charged. First, the excessive liberation of gas.

The free gas in the liquid gives a milky appearance. If the current be strong the evolution of gas amounts almost to boiling of the liquid. Second, the density of the liquid. As the battery becomes charged the proportion of acid increases and the solution becomes heavier. At the beginning of the charge the density may be 1.16, and as the charge increases the density of the liquid increases to about 1.22. This change in the density is readily shown by the acidometer and when measured by the Baumé gauge will have a range of about six degrees. At the beginning of the charge the specific gravity will be low and will be about twenty degrees Baumé. The reading will go up to about twenty-six degrees when the cell is fully charged. The third indication of the strength of the charge is shown by the voltage of the cell, which gradually rises to two volts and over. When a pressure of 2.25 volts is attained the cell is fully charged. This pressure, by the rapid reduction of the free gas, soon drops to about two volts where it remains till the cell is discharged.

It would seem that from the great variety of modern accumulators other substances than lead and sulphuric acid might be successfully used, but it is a noticeable fact that while other materials have been employed and in some instances have cheapened and simplified the construction, they have not, except in a few instances, attained commercial importance. The only cells which may be said to compete with the lead-sulphuric-acid type are those of the lead-zinc type. In these cells the lead forms the positive and the zinc the negative plate, and the electrolyte is a zinc-sulphate solution.

The other less important varieties are lead-copper in a copper-sulphate solution, spongy antimony and oxidized antimony in a sulphuric-acid solution, manganese dioxide and iron in an iron-salt solution, and many others made up in like manner of various metals and solutions. The action and efficiency of some of these is so feeble as to be scarcely distinguishable from a primary battery. As a matter of fact many so-called primary cells are capable of being used as storage cells under certain conditions, but their efficiency does not warrant that they be classed as storage cells. The lead sulphuric-acid type is the cell most generally employed, and the principal difference to be found in the great variety upon the market is the method of holding the active material in contact with the lead plate. The simplest are constructed in such a manner that the lead of the grid mechanically holds the active material within it. A sectional view of the grid would show a depression or hole more or less dove-tail in shape for holding the active material. Another style will show a hole in the plate with a constricted center so that the active material is somewhat the shape of an hour-glass. Another and a very popular cell has its plate made with outstanding and upturned leaves which hold the active material between them, and still another style has the plate cast about prepared pastilles which are afterward converted into active material by a chemical process. By the last method there is a closer union between the lead salt and the plate than can be obtained by the pasting process.

The principal aim of all manufacturers of storage

cells is to construct a plate which will present a large active surface, and at the same time withstand a heavy discharge without losing the active material. During both the charging and discharging of the cell, chemical and electrolytic actions are operative, and this is proportionate to the amount of current. During the charging of the cell there is a contraction and during the discharging an expansion of the plates. An intermediate step in the discharge of the cell is the formation of lead sulphate, and also the evolution of gas, both of which act expansively upon the plates. This tends in the course of time to loosen the active material, and to change the shape of the plates. Many plates are so constructed as to still retain the active material, even though it may be loose, but it is more difficult to prevent the buckling. The latter is due to unequal expansion, and can only be prevented by an even proportion and distribution of active material and the lead matrix. The warping of the plates has been one of the most serious faults of the storage batteries, and, knowing that there must be more or less of it, the manufacturers pay close attention to the details of insulation, so that in the event of buckling it will be impossible to do so to the extent of touching a neighboring plate.

When the battery is to be used for stationary purposes, the plates are stood upright and insulated from one another by vulcanite rods or perforated sheets of cellulose. When used for portable purposes, however, it is best to arrange the plates horizontally, and those cells which are designed for the latter purpose have their grids especially constructed, and an insulating

material is used which will certainly prevent contact of the plates and a penetration of the salts which loosen in the course of time. Asbestos cloth and cellulose are largely used for insulating purposes in such cases.

If the cells are stationary, and are not too large, the containing vessel should be of glass so as to allow free inspection of the condition of the plates. When used for portable purposes, however, the vessel should be of hard rubber and covered with a plate of the same material. This is let into the top and sealed around the edges with melted paraffine and beeswax. A small vent is provided for the escape of gas.

If the construction of the principal types of storage batteries were to be examined somewhat in detail, a noticeable feature, apparent in all of them, is the effort to use a grid which will mechanically hold the active material in its place and at the same time present a large quantity and area of the material to the action of the electrolyte.

The American battery uses a grid having outstanding ribs which contain the active material between them. The walls of the ribs are parallel, and if the cell is not put to portable use, the adhesion of the paste to the lead is sufficient to keep it in place. Both sides of the plate are ribbed alike. By this means the contraction and expansion goes on equally, and such a plate will not warp unless the active material is very unevenly applied. To insure a more even distribution of material and a better union with the plate, the active salt is formed on the plate by an electrochemical process not unlike the Planté method till the interstices between the

ribs are filled. A sectional view of the American plate is shown in Fig. 62.

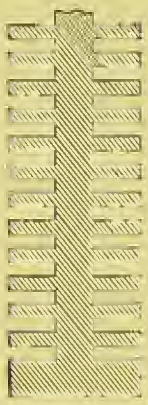

Fig. 62.—Sectional View of Plate.

Each plate has an upstanding lug as shown in Fig. 63 for making the connections. This lug is slotted for the purpose of receiving a heavy strip of lead which forms the common terminal of all the plates of the same kind in the cell. When the plates are assembled, they are so arranged that the lugs of the positive plates come on one side and those of the negative on the other, as shown in Fig. 64. The common connecting piece has a long and heavy strip which is intended to reach to the next cell and be firmly bolted to a like strip from that cell.

Fig. 63.—Plate of American Cell.

In connecting up the cells, the strip from the positive plates of one cell is connected to the one from the negative plates of the next cell, and this order followed throughout. In this way a free strip remains at each end of the series which will be found to be of opposite polarity. These then form the connecting terminals for the outside circuit.

Another form of storage cell quite similar to the one just described is the Willard. The plate of this cell as shown in Fig. 65 differs from the other only in respect to the angle at which the ribs or shelves stand.

They are inclined upward at an angle of twenty degrees and are also slightly curved. By this means a good mechanical support is obtained for the active material. Both sides of the plate being treated alike, there is no warping. The active material is electrochemically formed, and thus additional strength of fixation on the plate is secured.

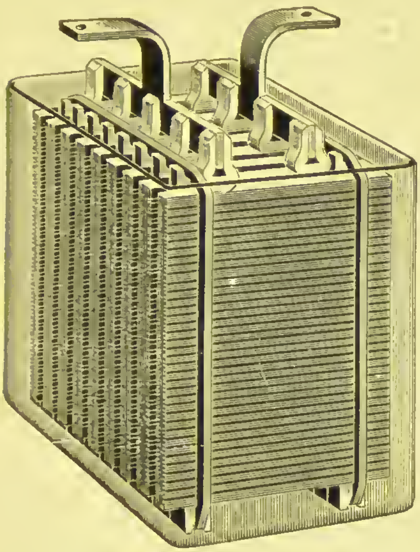

FIG. 64.—AMERICAN CELL.

The next cell to claim attention is one widely different in the method and details of construction from the foregoing, and yet, when studied, the chemical and electrolytic action is the same. The cell is called the Chloride Accumulator and is made in the following manner:

Lead chloride and zinc chloride are mixed together and cast into molds which give it the form of blocks three-quarters of an inch square by five-sixteenths of an inch thick. These are to be used in the negative plates. For the positive the lead-zinc chloride is cast into lozenge-shaped pieces about the same size as those for the negative. It is customary to cast the buttons for both plates in groups of four. These groups are then arranged in a mold and a mixture of lead and antimony under heavy pressure is cast around them.

The buttons having been slightly beveled in the original casting are now rigidly fixed in the lead matrix.

The next step is the conversion of the lead-zinc chloride into spongy lead, which is chemically done by immersing the plates in a dilute solution of zinc chloride alternating them with sheets of metallic zinc. The battery plates and the zinc sheets when brought in contact produce a short circuit, which electrochemically removes the zinc chloride and the chlorine from the pastilles of the plate.

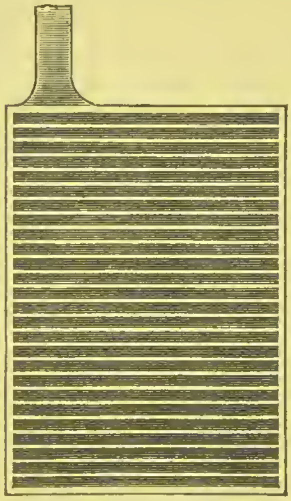

FIG. 65.—THE WILLARD PLATE.

This leaves the pastilles in the form of spongy lead not only closely united with the lead frame of the plate, but in such a fine state of division as to present a very large area for electrochemical action. The spongy lead is crystalline in character, the crystals being arranged with their long axes pointing outward. This affords ready means for electrolytic reactions without danger of breaking up the pastille. It also presents the maximum surface for the same, thereby largely increasing the cell's capacity without adding to its weight. A view of one of these cells is shown in Fig. 66.

While a plate constructed in the foregoing manner will not easily lose its active material, an insulating sheet of asbestos cloth is placed between each plate as an additional safeguard. The cloth allows good cir-

culation of the electrolyte, and does not appreciably increase the internal resistance. When these cells are intended for portable use rubber jars are used instead of glass. Six such cells are shown in Fig. 67.

The Silvey battery takes its name from its inventor, W. L. Silvey. The distinct features of this cell are the method of preparing the active material and the plan of combining the several plates in the cell.

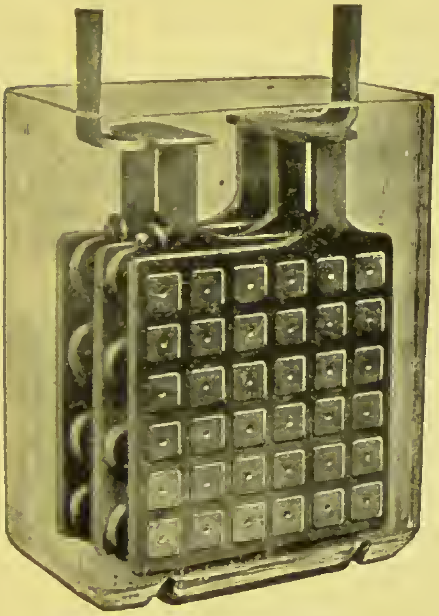

FIG. 66.—THE CHLORIDE CELL.

The grid is of the usual perforated type. The active material which fills the perforations is prepared by employing what is known as *lead dust,* finely divided lead, mixed with sulphate of soda, five to eight per cent. by weight and just enough water to form a thick paste. When this is hung up to dry, the sulphuric acid of the sodium sulphate attacks the finely divided lead forming lead sulphate, which permanently binds the paste together, and also causes it to become adherent to the metallic grid. The sodium sulphate thus furnishes the sulphuric acid necessary for further forming of the plate, and also produces a porosity of the plate, a very important feature.

After the lead sulphate has formed, the plate is immersed in water which dissolves out the sulphate of soda,

leaving a very porous filling of finely divided metallic lead and lead sulphate. The plates are then immersed in a bath of sulphuric acid, one part to four of water, which completes the sulphating process. They are then ready for mounting in the cell and charging. In passing a current through the cell, the plates are converted into either positives or negatives according to the direction of the charging current.

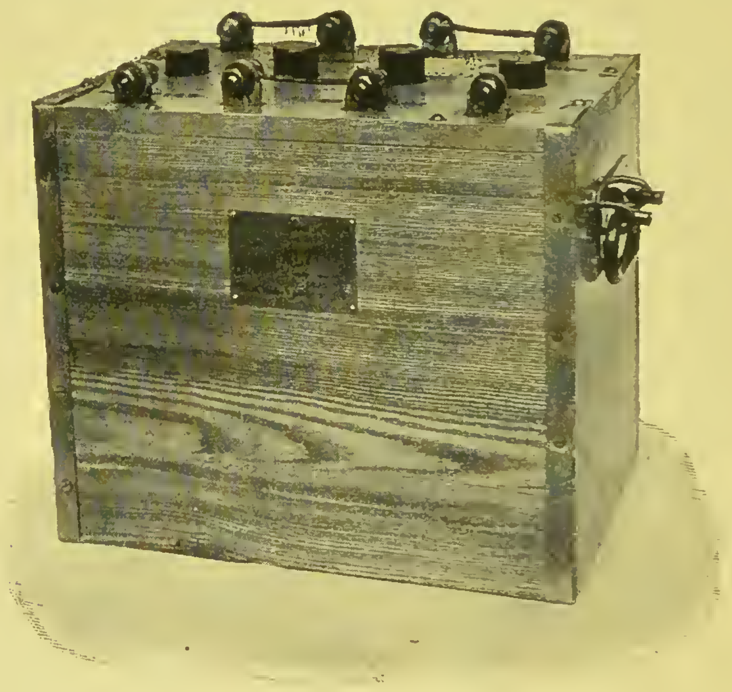

FIG. 67.—THE CHLORIDE BATTERY.

The Silvey cell possesses another advantage in the manner of assembling the plates in the completed cell which is shown in Fig. 68.

Instead of arranging them perpendicularly, as in most cells, they are placed horizontally. Each plate,

which may be either square or round, has a recess in one of its edges the object of which is to allow the connecting bar of the neighboring plates to pass through without contact. The plates are all molded alike, but the alternate ones are reversed, and in this manner a bar connecting all the plates on one side will be of one polarity and the bar connecting all the plates of the other

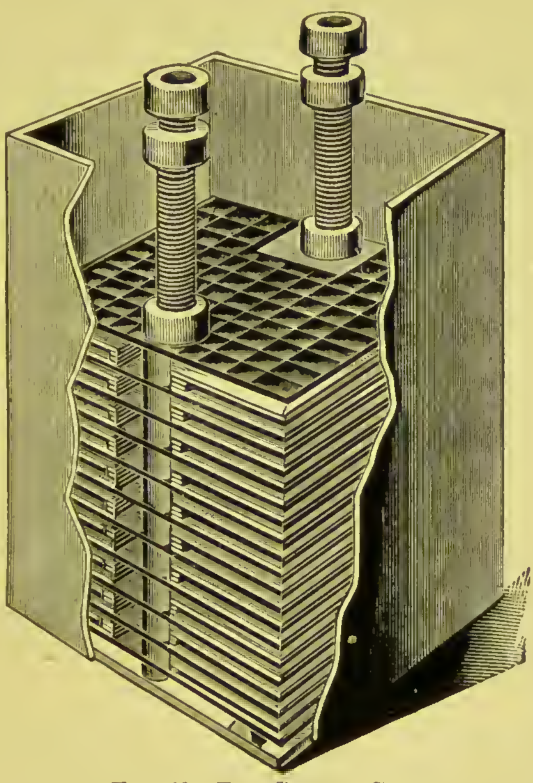

FIG. 68.—THE SILVEY CELL.

side will be of the opposite polarity. The plates are insulated from one another by means of a thin board of cellulose.

This cell is especially fitted for portable use inasmuch as any loosening of the active material cannot produce a

short circuit, by reason of the horizontal arrangement of the plates.

A cell widely different from the foregoing is known as the High Tension Cell. This is an analogue of the voltaic pile. The voltaic pile consists of a column of plates of zinc, absorbent insulator, and copper, in the order named. This was a primary battery. In the high-tension battery the zinc plate is replaced by a layer of peroxide of lead, the absorbent material is essentially the same, and the copper plate is replaced by the layer of spongy lead. We thus have in the most compact space the essentials of the storage battery. Instead of there being a vessel to contain the plates, both sides of which are the same electrically, the lead plates are themselves the cell divisions, and the opposite sides are oppositely charged. One side of each plate is coated with a layer of lead peroxide, and the other side is in the form of spongy lead. When these plates are arranged in a pile with the positive side of one plate facing the negative side of its neighbor, but insulated from one another by an acid absorbent pad, each plate has twice the usual electromotive force, and this has given it the name it bears.

A second feature of this cell is the position of the plates; they are arranged horizontally instead of perpendicularly. They also admit of being firmly bound together, so that the tendency to warp is overcome. The electrolyte is held between the plates by a thick pad of absorbent material, and there being no free liquid, the battery is especially suitable for portable purposes.

A third feature of this cell is its comparatively light weight. A cell of twenty-five ampere hours weighs approximately one hundred pounds, while cells of the usual type weigh almost twice as much.

A twenty-eight volt, twenty-five ampere hour battery is shown in Fig. 69.

FIG. 69.—HIGH-TENSION PILE OF TWENTY-FIVE AMPERE HOURS.

The edge of each lead plate is seen, and between these somewhat further in is the edge of the absorbent acid pad. There are no connections between the plates as in other cells, and the connections for the external circuit are made to lips extending from the uppermost and lowermost plates. That from the lower plate is usually carried to the top of the pile but carefully insulated from the edges of the plates which it passes.

CHAPTER V.

The Rheostat.

The regulation of the flow of current, and the control of instruments using it, are accomplished by means of the rheostat. This appliance produces the same effect in electricity that the valve does in hydrostatics. It affords a convenient and accurate means of modifying the strength of the electric current to suit the requirements of the instrument under operation.

The rheostat is, strictly speaking, a compact resistance to the flow of current with a ready means of cutting more or less in or out of the circuit. The effect of introducing resistance in the circuit is to diminish the flow of current, which causes diminished activity of the instrument or process which is in series with the rheostat. In like manner the opposite effect upon the instrument or process is produced by cutting the resistance out of the circuit. If an arm is so arranged that in describing an arc it will play upon successive points of contact between which there is a continuous chain of resistance, then turning the arm in one direction will introduce resistance into the circuit and turning it in the opposite direction will cut it out.

The form of rheostat most frequently met with is made upon this principle, and is diagrammatically shown in Fig. 70, where the resistance consists of a

continuous length of wire with contact buttons equally distributed, and is used to regulate the speed of a motor. When the lever is on the first button, as shown, the current must flow through all the coils of the rheostat and the resistance is greatest. The motor now runs at its slowest speed. When the lever is pushed forward to

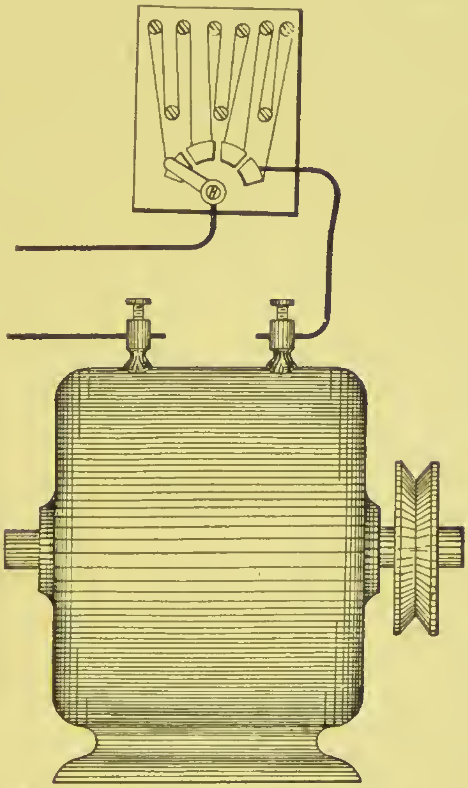

FIG. 70.—DIAGRAMMATIC ILLUSTRATION OF RHEOSTAT AND MOTOR.

the second button, the current no longer flows through the coils of wire betweeen buttons one and two, and this branch being cut out the speed of the motor is increased. In this manner the speed of the motor is increased as the lever is pushed over the successive buttons till the

last one to the right is reached where the fullest speed is attained. In the same way heating appliances and electrolytic processes are regulated by means of the rheostat.

The material used for resistance is most commonly a metal wire or ribbon of comparatively high specific resistance. Carbon and water also make very good resistance, and in some cases are even more suitable than metal. All metals increase their resistance with a rise of temperature, whereas carbon and water decrease their resistance as they become heated. A metal of high specific resistance is selected for this purpose, because of the economy of material and space. Silver and copper wire, while being the best conductors, if fine enough and long enough, will offer considerable resistance to the flow of current, but these are not used for resistance because of the comparatively large quantity necessary to secure the same amount of resistance that would be given by a short length of wire of higher specific resistance.

When metal is employed, one is selected which will also withstand a high temperature without changing form, as in practice the rheostat dissipates the surplus electric energy in the form of heat. For this reason, the higher the temperature allowable, the greater can be the resistance in a given space, and if in the construction of the rheostat ventilation or means of rapid radiation is observed, one of large electrical capacity can be made in a very compact form. The heating of the rheostat is, therefore, a part of its proper function, and so long as it is within safe limits it should not cause concern.

The metals most commonly employed for resistance are german silver and iron. If copper be considered as one, the relative resistance of iron would be six, and german silver thirteen times that of the first named metal. Both of these metals have a high melting point, and have a comparatively high resistance. There is a feature peculiar to each of these metals, however, that is not to be overlooked when used for electrical resistance. As previously stated, most metals increase their resistance as they become heated, and for some purposes this may be desirable, but for purposes of motor regulation, for testing, and the like, the resistance should not perceptibly increase with the heat. The resistance of iron increases about five-tenths per cent. with a rise of temperature, whereas german silver only increases four-hundredths. For this reason iron is used only where cheapness of construction is desirable, and a uniform resistance is of little importance. The percentage of variation of the resistance of german silver, on the other hand, is so small that it need not be considered when this metal is used in the practical construction of rheostats for ordinary purposes.

The alloy, platinoid, which consists of german silver alloyed with one or two per cent. of metallic tungsten, has sixty per cent. higher resistance than german silver, and has even a smaller percentage of temperature variation of resistance.

There has recently appeared upon the market a metal made especially for resistance purposes, known as "climax" resistance wire, which has forty-eight times the resistance of copper. This enables a high amount

of resistance to be contained in a very small space. The metal also has a high fusing point, differing but little from german silver while its temperature variation is even less than that of the latter metal. For the purpose of testing, an alloy composed of platinum one part and silver two parts, which has a resistance sixteen times that of copper, has a temperature variation of only three-hundredths per cent.

The relative resistance and temperature variation for each degree centigrade of the common metals is shown in the following table from Matthiessen.

RELATIVE RESISTANCE AND TEMPERATURE VARIATION OF METALS.

Metal.	Relative Resistance.	Variation of Resistance.
Silver	1.	0.377
Copper	1.063	0.388
Gold	1.369	0.365
Zinc	3.741	0.365
Platinum	6.022	0.428
Iron	6.460	0.500
Tin	8.784	0.365
Lead	13.05	0.387
German silver	13.92	0.044
Platino-silver ..... 1 to 2	16.21	0.031
Antimony	23.60	0.389
Mercury	62.73	0.072
Bismuth	87.23	0.350

The most reliable and uniform rheostats in commercial use are those in which german-silver wire is the

resistance material. This in the older forms was coiled into springs from one-quarter of an inch to an inch in diameter according to the capacity of the rheostat. These coils were suspended in such a manner as to insure free ventilation, and thus secure a large dissipation of electric energy without endangering the wire of the rheostat or the surrounding objects. If the coils are vertically suspended and the upper and lower encasements well perforated, a draught of air is established by the heating of the coils and the radiated heat is rapidly carried off.

A fire-proof rheostat can be made in a very easy manner by using a common school slate for the switch-board. The slate is fire-proof and a very good non-conductor of electricity. The coils of wire are stretched upon one side of the slate and the lever, or movable arm, is mounted upon the other. If the wire is not too small and does not become too highly heated, tacks may be driven in the wooden frame, and the coils laced from side to side till the back is covered. A distance of half an inch should separate the coils, so that they cannot touch laterally. If the wire is so small that it becomes dangerously heated, the wooden frame should be removed and the coils fastened to the slate either by staples or by being caught in notches in its margin. The lever is mounted on the opposite side of the slate which we will call the front. It is pivoted at its lower end, and the contact buttons, which may be screw-heads, are arranged in an arc near the upper edge of the slate in such a manner that the lever slides smoothly from button to button. The first button to

the left should be blank and in this way the rheostat can also be used as a cut-off for the current. Beginning with the second button, the connections are made upon the back of the slate with the coils by means of short lengths of insulated underwriters' wire in such a way that the proper number of steps is obtained. If there are eight coils on the slate with the wire ending at the top and six contacts give the necessary steps, the first one being blank, the coils may be fastened to the contact buttons themselves provided they project far enough through the slate. The rheostat can then be fastened in its place. Porcelain shutter knobs are an excellent means of insulation, and a screw through each corner of the slate and one of these knobs will make a fire-proof support, as the slate will stand away from the wall the thickness of the knobs. A rheostat should always be placed with the pivoted end of the lever downward, for, in the event of the lever becoming loose, it would not slide upon a live contact button, as would surely happen if the rheostat were placed with contact buttons at the bottom. The two wires for the circuit are to be connected, one to the pivotal screw of the lever and the other to the last button itself.

In making the connections on the back the second button (the first being blank), should represent one end of the resistance wire and the last button should represent the other end, while the intermediate buttons represent equally distant tappings of the resistance wire. In this way the strength of current is increased in equal steps as the lever passes from button to button.

The calculating of what resistance would be proper

for a given purpose can best be shown by an example. Let us suppose that it is desirable to make a rheostat for regulating a one-eighth horse-power motor on the one hundred and ten volt current. Such a motor requires about one ampere to operate it at full speed. If our rheostat is to reduce the speed to about one-half, with intermediate speeds, an equal amount of resistance will be necessary. The motor at full speed offers ninety-three ohms' resistance, and our rheostat must have about the same. If we use climax resistance wire, whose resistance is forty-eight times that of copper, and it is not allowable to attain a higher heat in the rheostat wire than three hundred degrees Fahrenheit, thirty-gauge wire will answer, for one ampere of current will raise thirty gauge of this wire to that temperature. It now remains to estimate what length of thirty gauge will give about one hundred and ten ohms' resistance. Thirty gauge of climax resistance wire at three hundred degrees Fahrenheit has a resistance of five and eight-tenths ohms per foot. Dividing the total resistance by the resistance per foot, gives eighteen and nine-tenths feet as the required length of wire. In like manner a german-silver wire rheostat can be estimated; for, since german silver has one-third the resistance of climax resistance wire, the same length of a thirty-five gauge wire, which has about one-third the cross-section of a thirty-gauge will answer. Or, a wire of the same size, but three times the length will give the same resistance as climax with less heat.

In the manufacture of commercial rheostats the principal objects sought by all makers are, first, the use

of a resistance material which will withstand a high temperature; and, second, a means of rapid dissipation of heat, for it is by these means that economy of space and material is secured. One of the most popular instruments upon the market is the Carpenter enamel rheostat. A sectional view of one of these is shown in Fig. 71.

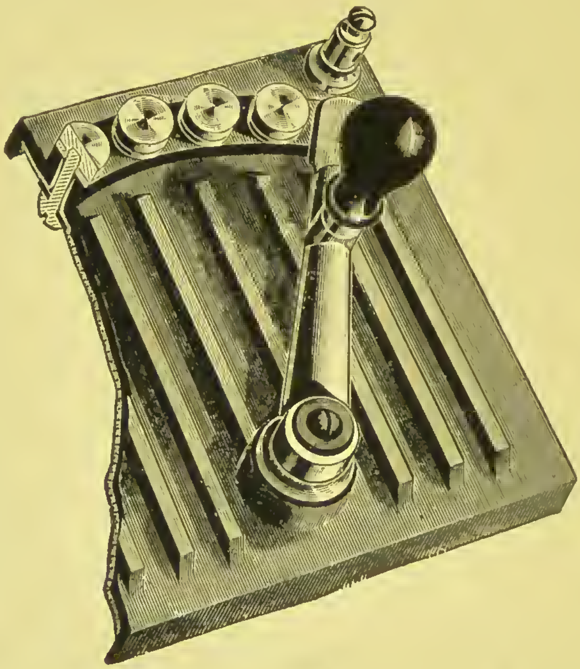

FIG. 71.—SECTIONAL VIEW OF CARPENTER ENAMEL RHEOSTAT.

This appliance is probably the most compact and efficient of all. It is, moreover, fire-proof. The base is of cast-iron with legs an inch or more in length, which hold it from the wall. Upon the front of the casting are outstanding ribs, the function of which is to cause rapid radiation of the heat. Upon the back are two or more coats of porcelain enamel. A first coat is applied

and baked. This insulates the iron from the wires, which are next to follow. The wires, having been bent into very short curves and annealed, are laid upon the first enamel coating and a second coating of enamel is then applied and baked. This brings the wires into close relation with the iron base, and yet they are electrically insulated therefrom by means of the porcelain enamel. This insures rapid conduction of the heat to the iron whence it is radiated. While considerable heat is radiated from the porcelain side of the rheostat, much more is dissipated by means of the large radiating surface offered by the ribbed front.

While the enamel is closely adherent to the iron the latter is slightly concave upon the side to which the porcelain is applied, which further insures against detachment during heating and cooling.

Another rheostat is made by the same company which in some respects is better than the one just described. It will withstand rougher usage, and, except its being somewhat thicker, does not occupy any more space than the enamel rheostat. A thick plate of enameled slate forms the front of the instrument. The wires are strung upon the back of the slate in fine coils and are insulated from one another by asbestos paper. A close fitting iron box is tightly screwed to the marble front, which is then completely filled with fine sand and sealed. The sand serves to conduct the heat from the wires to the casing whence it is radiated. The wires are in close contact with a conducting medium which by its fine state of division allows them freedom to expand and contract during heating and cooling.

A rheostat known as the Ironclad resembles the enamel rheostat in appearance very much. This is shown in Fig. 72.

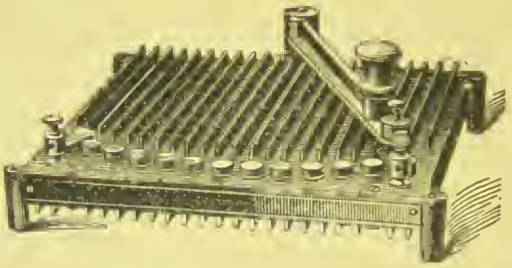

FIG. 72—IRONCLAD RHEOSTAT.

The resistance is in the form of a wire which is wound on a flat piece of slate. This occupies the center of an iron box, the rest of the space being filled with a cement which is a non-conductor of electricity. The cement holds the slate in its position, and at the same time conducts the heat from the wire to the case whence it is radiated. In order to insure rapid radiation of the heat both the front and the back are deeply ribbed. This rheostat is fire-proof and will withstand a very heavy current for a few minutes without damage, at the same time dissipating as much energy as any other of the same proportions. The cement filler of this rheostat will withstand as much heat as it would be safe to put upon the wires. The author has made rheostats upon the same principle, using a filler composed of Portland cement one part, and marble-dust, three parts. This will withstand considerable heat without disintegration, but it is a slight conductor of electricity. This does not affect the working of the appliance provided the binding posts and lever are insulated from the iron casing.

The objection to this form of rheostat is that the hygroscopic nature of cement or sand invites moisture which may in the course of time provide the conditions for electrolytic action, and thereby destroy the resistance wires.

The Universal Enamel rheostat is made up of a large number of steel discs which contain resistance wire imbedded in enamel. The frame of the rheostat is a round iron plate as shown in Figs. 73 and 74.

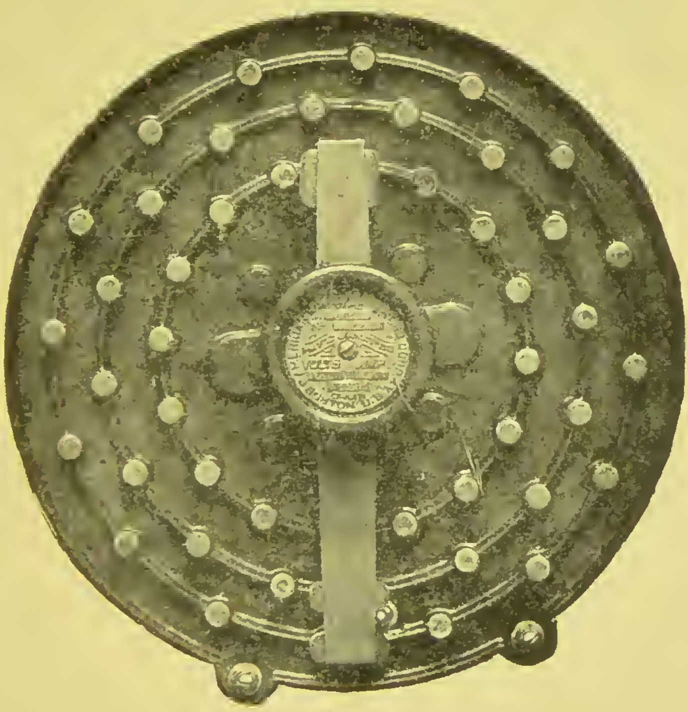

FIG. 73.—FRONT VIEW OF UNIVERSAL ENAMEL RHEOSTAT.

It is ribbed in front for the purpose of more rapidly radiating the heat. Each disc has a hole in its center through which a flat-headed bolt passes. The head of the bolt is caught upon the front of the iron plate. The disc is slipped upon the bolt from behind, and a nut

binds the unit in place. The bolt heads are insulated from the bed-plate, and when all are made tight they are dressed off to an even height so as to serve as contact buttons upon which the lever will play.

FIG. 74.—BACK VIEW OF UNIVERSAL ENAMEL RHEOSTAT.

Each of the discs forms a unit of resistance, and thus it is an easy matter to connect them in series or parallel for different requirements. It also allows of the quick replacement of a new one for one that may be burnt out, without taking the entire rheostat apart.

The Wirt rheostat as shown in Fig. 75, somewhat resembles the one just described, but is quite different in its details. It employs a bed-plate of iron which, like the others, is ribbed for the rapid radiation of heat. The resistance is in the form of a continuous ribbon,

without break or joint, wound into fifty or more coils which constitute the steps of the rheostat. The successive layers of ribbon are insulated from one another by a layer of mica and the whole pressed in close contact with the bed-plate.

This rheostat, like the Ironclad and the sand rheostat will withstand a heavier current for a short time than can be safely used in an enamel rheostat, for the reason that the conductors have latitude for the sudden expansion. This is a feature which cannot be provided for where the wires are imbedded in enamel. A sudden rush of current in an enamel rheostat will cause the wires to expand before the investing enamel and iron base have become heated. This sooner or later causes the enamel to scale off. The best enamel rheostats, however, have the wire bent in a continuous curve from beginning to end. In this way the expansion takes place in a very short arc of a circle, and in so doing, the movement of the wire is so little that the enamel will withstand it without flaking off.

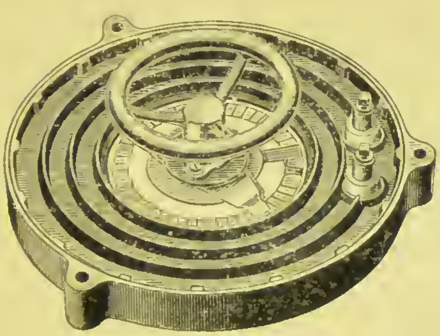

FIG. 75.—THE WIRT RHEOSTAT.

A sixth form of rheostat is the carbon. While carbon is a conductor of electricity, it may not be called a good one, and if fine enough offers considerable resistance to the electric current. The high resistance and high fusing point of carbon make it the best filament for incandescent lamps. The resistance of carbon may be varied

in two ways; one by varying the cross-section of the rod or filament, and the other by incorporating a non-conductor in the mixture during the time of its manufacture. A rod of very high resistance can be made by mixing pulverized fire-clay with the carbon. When this is glued together by the use of a little molasses and baked, the rod will withstand a very high heat and can be made to furnish considerable resistance in a small space.

A carbon rheostat differs from a wire rheostat in one particular which for general purposes is not objectionable and for some purposes is a decided advantage. Carbon, unlike metallic conductors, decreases its resistance as it becomes heated; so that in the operation of appliances and processes which call for a gradual increase of current, the carbon rheostat automatically decreases its resistance to a small extent between each move of the rheostat lever.

In the manufacture of a carbon rheostat the rods should be large enough to withstand the usage put upon them. It is therefore customary to make up the rod very largely of the inert matrix, so that one of large cross-section will also possess considerable resistance.

A carbon rheostat which embodies the above principles, is upon the market under the name of the Raster. The resistance is obtained by using a mixture of carbon and a high-fusing non-conductor. This is molded into oblong rods from six to ten inches in length and baked. The rods are then laid side by side, but separated from one another by a small block of the same material at one end, and a block of plate glass of like

dimensions at the other. The blocks of carbon and glass alternate at both ends in such a way that the current finds a path from rod to rod through the carbon blocks, the path being a continuous one throughout the full lengths of the rods. The glass blocks serve to insulate neighboring rods at one end and at the same time keep the rods in regular order. The whole is then firmly clamped as one unit in an insulated iron frame

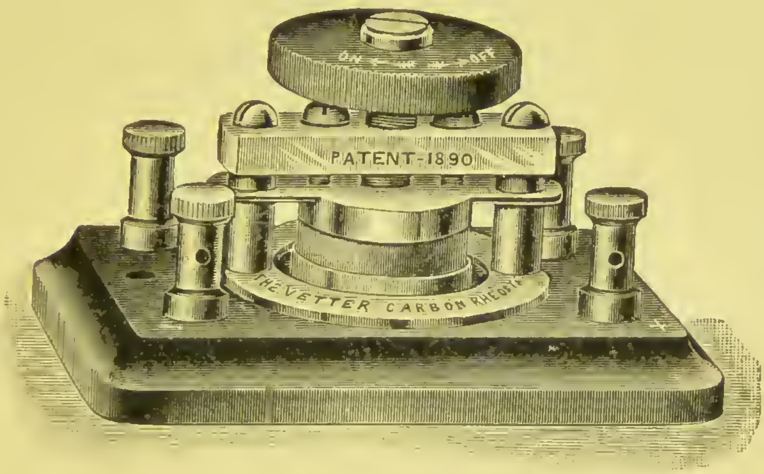

FIG. 76.—CARBON RHEOSTAT.

and encased in a ventilated box or switchboard. Connections are made to the rods at desirable intervals for the several steps which are represented by the buttons on the front of the board.

Another form of carbon rheostat is in use where a simple one with a means of very gradual increase of current is desirable. This consists of a vessel or tube which is a non-conductor of electricity such as rubber, or porcelain filled with pulverized carbon. The vessel is closed at both ends with metallic plates, one of which is movable. The tube or vessel is filled with pulverized

carbon, and the movable plate is made to bear upon the carbon by means of a screw. The carbon, being in a fine state of division, is not a good conductor because of the light contact between the particles. If pressure is brought to bear upon the mass, the contact between the particles increases, and its conductive property is like-

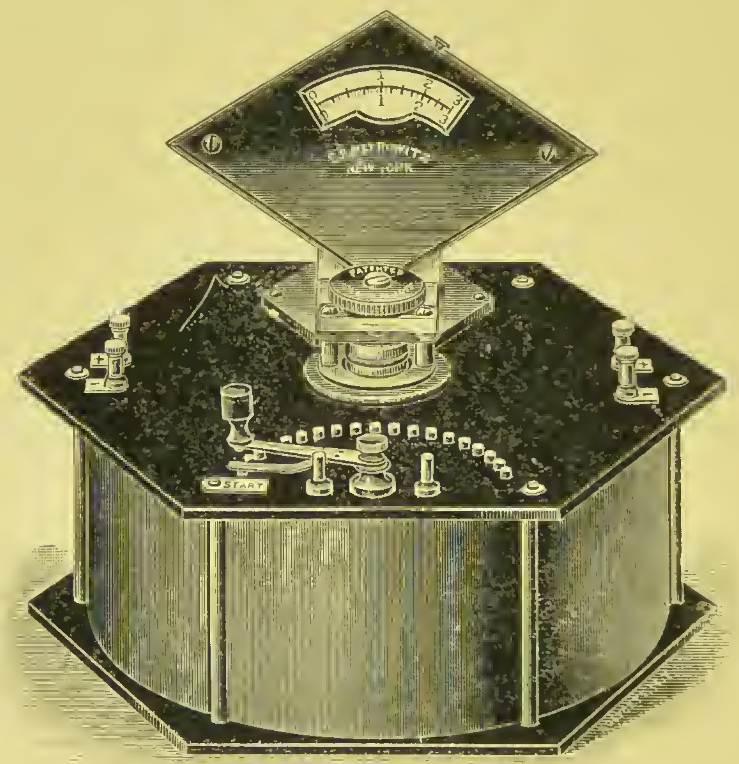

FIG. 77.—CARBON RHEOSTAT IN CASE FOR THERAPEUTIC PURPOSES.

wise affected. By this means an increase of current can be obtained which is perfectly smooth. It does not increase by steps but gradually as the screw presses the end plate upon the carbon.

Another method of using pulverized carbon is to

enclose it in a flexible rubber bulb or tube having metallic contact plates at either end to which the conductors are attached. If the ball is placed in a clamp in such a manner that the plates can be pressed toward one another, the increase of pressure upon the carbon and at the same time the increase in its flat diameter decreases the electrical resistance between the plates. Such a rheostat is shown in Fig. 76.

The carbon rheostat just described is very simple, and

FIG. 78.—GRAPHITE RHEOSTAT.

when mounted in a case for therapeutic purposes makes one of the most compact appliances upon the market. Such a one is shown in Fig. 77.

Still another form of carbon resistance is in practical use. This is applicable where very high resistance is desirable, as for cataphoric operations and the like. The rheostat consists of a plate of ground glass or slate upon which a thin coat of graphite (a form of carbon) has been applied. The graphite is in the form of a cir-

cular path upon which a light bearing metal brush plays as it is turned around its pivotal point. The graphite path is not quite a complete circle. One end of it terminates upon a metallic plate to which connection is made, and as the brush sweeps around the path, the resistance increases until the other end is reached, when the full resistance of the graphite is operative. This form of carbon rheostat is shown in Fig. 78.

Graphite is also used in the form of a paste for resistance. The Willms current controller as shown in Fig. 79 is constructed upon this principle. A paste of

FIG. 79.—WILLMS CURRENT CONTROLLER.

graphite is forced into a circular groove in the plate of the instrument. Metallic pins extend through the plate from above into the graphite composition underneath. The resistance path is circular in form and the lever being pivoted in the center can sweep the whole length of the resistance in one revolution. In order to insure smooth and certain contact the traveling contact is

large enough to cover three or four of the pins at one time.

The very high resistance and the accuracy of its gradations make the Willms appliance of special value for testing and for cataphoric work.

The last form of rheostat to receive notice is the water rheostat. It is not generally known that water in its purest state is a non-conductor of electricity. It soon, however, becomes a conductor by the absorption of gases and impurities, but is still to be classed as a poor conductor for which reason it may be used as a resistance for rheostat purposes. The convenience and simplicity of the appliance and the many ways of modifying its resistance make the water rheostat one of the most useful forms, especially for experimental purposes. If two carbon or metallic plates to which electrical connections are made be suspended in a vessel of water and are put in contact with one another, an electric motor or suitable instrument which is in series with the electrodes will operate at its fullest capacity. If now the plates can be separated but still suspended in the water, it will be noticed that the motor decreases its speed proportionately to the distance between the electrodes. Or, the plates having been fixed at a short distance from one another, if dipped in the water will start the motor, and the speed will increase as the plates sink deeper. In water therefore, we have not only a resistance by which to vary the strength of current, but we have two ways of doing so; one by varying the distance between the electrodes and the other by varying the depth of immersion. Moreover, a suitable arrange-

ment of the plates may be made whereby they are moved together as they sink in the water.

Figure 80 illustrates a convenient form of water rheostat. The plates are fixed on either side of a block of wood and the whole suspended over the vessel. If the plates be counterbalanced by a cord running over pulleys to a weight, they can be easily lowered to any depth where they will remain. Fig. 81 shows a water rheostat of the other form in which the plates

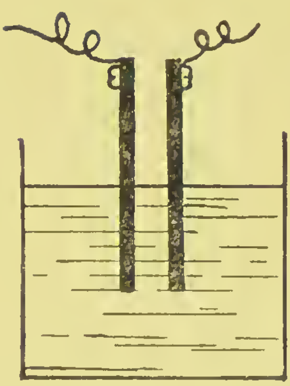

Fig. 80.

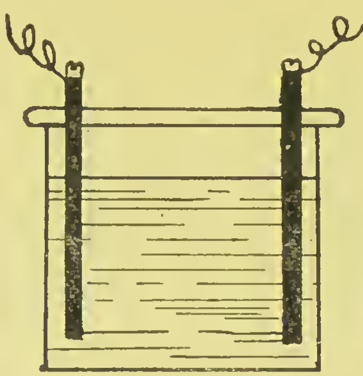

Fig. 81.

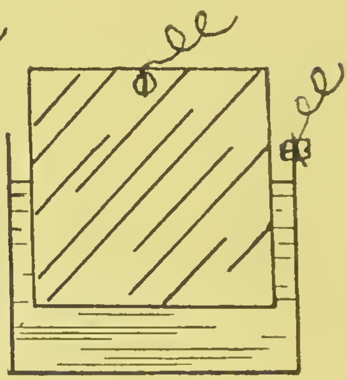

Fig. 82.

are suspended upon a glass rod upon which they are easily movable to and from one another. Fig. 82 represents probably the most convenient arrangement for securing a variable resistance. A metal vessel contains the water and also forms one terminal. A plate of metal is suspended over the center with a means for dipping in the water. One terminal is attached to the vessel itself and the other to the movable plate. Upon lowering the plate the circuit is established when it reaches the water. As it sinks deeper into the water the resistance decreases until the plate touches the bottom

when the entire resistance is cut out. By this arrangement there is a gradual increase of current from the time the plate touches the water till it reaches the bottom of the vessel. In Fig. 80 there would be a sudden increase of current if the vessel were of metal and both plates were to touch the bottom at once.

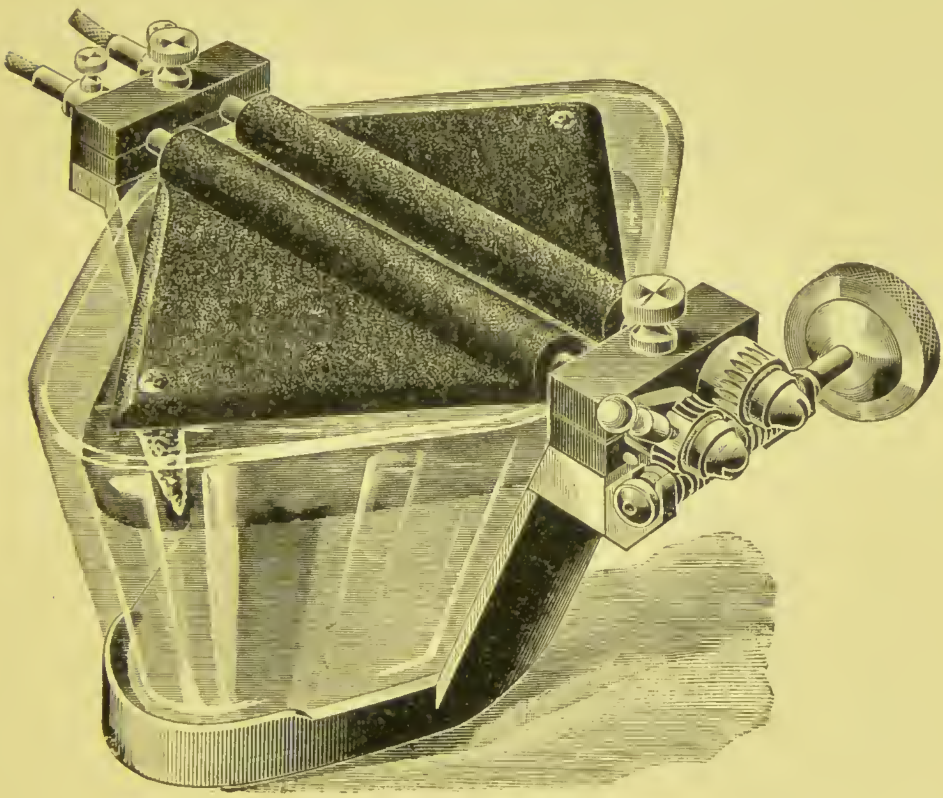

FIG. 83.—WATER RHEOSTAT.

The water rheostat is such a simple device that it can be constructed in a short time and with materials almost always at hand. For this reason there are but few water rheostats to be found upon the market. Fig. 83. however, represents one which is designed principally for physicians, and may be used wherever the

strength of current is to be varied without steps. Two V-shaped metallic plates to which the connections are made are pivoted at their upper border in such a manner that by turning a screw the pointed end of each plate dips down into the water contained in the vessel. When the points first touch the water the circuit is closed, but the resistance of the very small contact and the distance between the points at this time is so great that a very feeble current flows. As the knob is turned, the plates sink deeper in the water thereby exposing a larger surface. At the same time they approach one another which also reduces the resistance. The plates may finally be brought into contact with one another which cuts out all the resistance. This appliance reduces the resistance in two ways: one by bringing the electrodes towards one another, and the other by increasing the surface of the electrodes within the water.

A water rheostat possesses a property not met with in others. It can in a moment's time be arranged to give a large quantity at low voltage or a small quantity at high voltage. The resistance is varied in three ways: first by increasing the plate surface in the water as shown in Fig. 80; second, by varying the distance between the plates as shown in Fig. 81; and third, by acidulating the water. When the plate surface is increased it is the same as enlarging the cross-section of a metal conductor. The resistance of wire increases as its cross-section decreases. The deeper the plates are immersed in the fluid the greater is the surface they present, so that the resistance decreases with the depth of the immersion, and the operator has only to lower or

raise the plates to increase or decrease the volume of current.

By the second method, varying the distance between the two plates, the same thing is produced as lengthening or shortening a wire which conducts electricity. The resistance is greatest when the plates are far apart and decreases as they approach. By this arrangement the operator manipulates the volts more than the amperes, or in other words, the pressure more than the quantity. For this reason, a water rheostat whose plates are movable to and from one another is better fitted for using a low-volt instrument on a high-pressure current.

The water rheostat, unlike most others, is capable of very fine adjustment, since the current is increased by lowering the plates in the water or by bringing them together. If this be done by a screw as shown in Fig. 83, it will give even closer gradations for cataphoresis than can be obtained by more expensive appliances for this purpose.

The third means of varying the current is by acidulating the water. Water is a poor conductor of electricity when compared with the metals, but by adding an acid or a salt to it, it becomes a good conductor. An addition of nine per cent. of sulphuric acid increases the conductivity of the fluid about twenty-five per cent. It is not practical, however, to increase the acidity as a means of regulating, but by using the acid a rheostat of large capacity can be made from one of small capacity. To give the reader an approximate idea of the requirements for a water rheostat for various purposes,

a vessel holding a pint of water will be large enough to regulate a dental motor, mouth lamp, mallet, or gold-annealer. And one of a gallon capacity will be sufficient for regulating an electric oven, for fusing platinum, or for the cautery.

While sulphuric acid is recommended for modifying the conductivity of water, other agents may also be used for that purpose. An inspection of the following table will show the relative conductivity of various solutions.

Name of Solution.	*Specific Resistance.*
Sulphuric acid concentrated	5.32
Sulphuric acid with two volumes of water. . . .	.84
Nitric acid specific gravity, 1.36	1.45
Common salt concentrated	5.93
Common salt with two volumes of water. . . .	9.24
Zinc sulphate concentrated	28.00
Zinc sulphate, with two volumes of water. . . .	29.75
Copper sulphate concentrated.	29.82
Copper sulphate with two volumes of water. .	62.00
Distilled water	932.00

Another advantage of the water rheostat over all other forms is that it is fire-proof. There is no spark upon breaking the current and there are no contact buttons to corrode. The contact between metal and water is always good. The instrument can be easily made, is inexpensive, and requires no attention, except an occasional addition of a little water. If a stratum of oil covers the water, there will be little loss except that which results from electrolysis.

When a rheostat is used in series with an instrument as illustrated in Fig. 70, it is never possible to start at a point at which the pressure is absolutely zero. Moreover there will always be a spark upon breaking the current unless the resistance is very high. For some purposes, as for instance in cataphoric work and for the use of the cautery upon high-pressure currents, it is necessary to start at a zero point, and also to be able to break the current without a destructive spark. These two requirements are met by the use of what is known as a *shunt* rheostat. It has also, and not improperly, been called a "fractional volt selector." The word "shunt" is used in some countries in railroading just as "switch" is used in this country, meaning to turn off to a side track, and that is practically what is meant by the term in electricity. A current is a shunt current when it is parallel with another, and the method of regulating the strength of the shunt current is by placing a variable resistance in the main circuit which, when properly connected is then called a "shunt rheostat." It may be compared to a dam which is built across a stream of water for the purpose of operating a mill. The dam represents a resistance which has been placed in the circuit, the flume represents the shunt circuit, and the mill represents the electrical instrument under operation. The higher the dam is raised the more water will flow through the flume. And so it is with the electric current. The higher the resistance, the greater the amount of current shunted through the instrument.

The shunt rheostat is diagrammatically illustrated in

Fig. 84, and upon inspection it will be seen that it is an appliance which provides a main resistance, and a means of switching a part of the current through a second path which is parallel to a part of the main resistance. L and L are two lamps which offer the main resistance and in series with them is a rod, R, of poor-conducting carbon, which also offers consider-

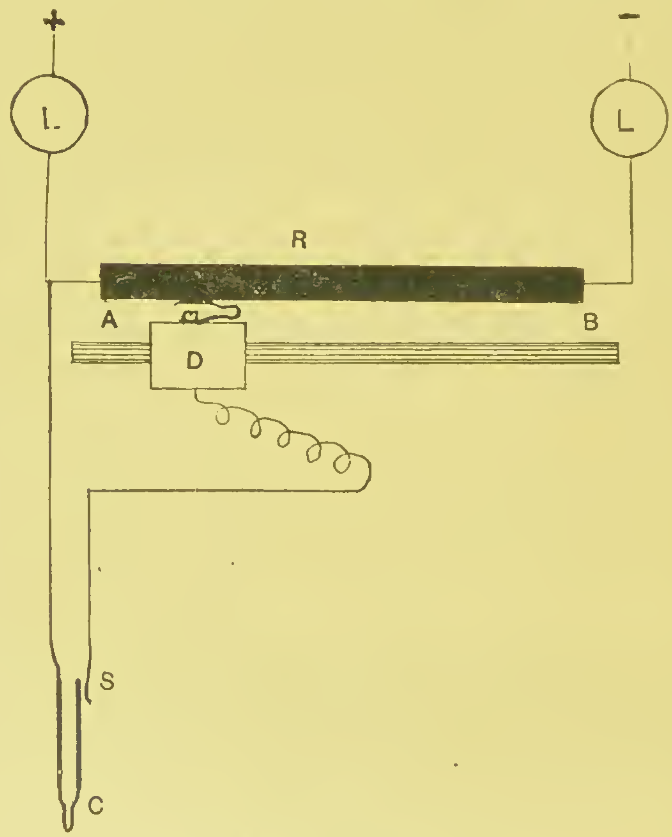

FIG. 84.—SHUNT RHEOSTAT.

able resistance. It is desired to heat the fine platinum wire C, which represents the platinum loop of a root-drier, with a current that can be started at zero and gradually increased. To do this one terminal of the

root-drier is attached to the main at A and the other terminal to a movable contact spring D. When D is at A no current will flow through C because there is no resistance between A and D. If now the contact D be moved towards B, resistance will be placed between A and D proportionate to their distance apart, and the current finding a second path through C, the switch S being closed, will divide itself and a part will flow through C. The division of the current in the case of two parallel circuits is always inversely proportionate to the resistance of the two paths. The resistance of the platinum wire remaining the same, more current will flow through it as D is moved toward B. If the resistance through the platinum loop and its conductors is equal to that of the carbon rod between A and D, then an equal amount of current will flow through each path. If, however, D be pushed towards B till the resistance between A and D is twice that of the platinum and its conductors, then the current will divide itself into thirds, one-third of which will flow through the carbon rod and the other two-thirds through the platinum loop.

While the shunt rheostat provides a method of increasing current from a zero point, it also possesses another feature which is of importance where a heavy current is used in an instrument which contains a switch. It would be impossible to use a cautery upon the one hundred and ten volt current, if it contained a switch in the handle, and the cautery circuit were not a shunt circuit, because of the tremendous spark that would exhibit itself at the switch when the circuit is

opened. When, however, the cautery circuit is made a shunt circuit to the main, as illustrated in Figs. 84 and 85, the switch S may be opened with scarcely any spark whatever. This is accounted for in this way: Upon opening the switch S, while it stops the flow of current through C, it does not open the main circuit and the current which was flowing through C prefers rather to flow through the carbon rod than jump across the break at the switch. For this reason there is but a small spark, if any, at the switch on the shunt circuit.

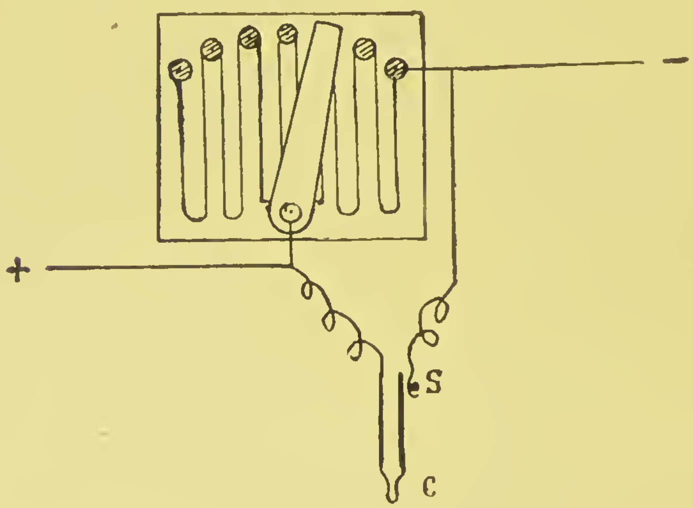

FIG. 85.—SERIES RHEOSTAT USED AS A SHUNT RHEOSTAT.

The shunt rheostat is not only valuable, therefore, because it provides for an increase of current starting from zero, and because of the small spark upon breaking the shunt circuit, but it possesses another property which, while it is not noticeable in most of the applications of a shunt current, is of the greatest importance in cataphoric operations. The shunt current appears

to be much smoother than a series current so that it is not as painful. It moreover seems that the greater the number of shunts that are in parallel with the cataphoric circuit, the less will be the undulations or unevenness of the cataphoric circuit, and the pain will on that account be less. In practice a stronger shunt current can be used than one which is in series with the resistance.

Any series rheostat can be converted into a shunt rheostat by making one connection to the lever and the other to the last button of the rheostat as illustrated in Fig. 85. In this case the lever is moved towards the left instead of to the right to increase the current in the instrument under operation. As it passes from button to button it cuts in more resistance and therefore shunts more current around through the other circuit. The shunt rheostat must always be employed in series with another or main resistance, and for that reason is a wasteful method of using current; but fortunately the dental applications which call for a shunt current of heavy amperage are limited to the cautery and root-drier, two instruments which do not come into daily use.

CHAPTER VI.

POWER.

THE electric motor is said to have been discovered at the installation of the Vienna Exposition in 1872, when by accident the mains from a dynamo on exhibition happened to become connected to another dynamo near by. It was noticed that when the first dynamo was put into operation, the second also began running. Nevertheless it is a well-known fact that a dynamo will act as a motor, and *vice versa,* and but little change is necessary to make one most efficient as either a dynamo or motor. The two are so nearly alike that the description of the dynamo in Chapter V. will answer also for the general details of the motor.

The dynamo is rated in kilowatts, while the motor is rated in horse-power, for the reason that the dynamo generates electricity whose output is estimated electrically by the term watt, while the motor converts electricity into power, and for that reason its output is reckoned in horse-power.

The motor to all external appearances resembles the dynamo and consists of a field, armature, commutator and brushes, if a constant-current machine. If it is to be operated by an alternating current, then, like the alternator, the brushes are wanting. The winding of the motor is also similar to that of the dynamo. It

may be series wound, shunt wound, or compound wound.

The field of the first small motors was of the horse-shoe type. There was no attempt at enclosing the armature as was later done for the purpose of producing a stronger field, and at the same time making the appliance dust-proof. This part of the motor was formerly made of the softest cast iron, but, owing to the great changes in the designs, many manufacturers are now making the field of laminated iron. This has the advantage over cast iron of being more highly magnetic, and of not becoming heated.

All the smaller motors are of the two-pole variety; in fact, only the very largest motors have four or six poles. In this respect dynamos and motors differ. All the motors with which the dentist has to do have but two poles. The motor may be entirely encased as with those used for driving lathes, and they may have the appearance of having four poles, but upon examination they will be found to have but two.

The armature is precisely the same as that employed in the dynamo. It may be a ring or Gramme type, or it may be a drum or Siemens. While, in the course of the improvement which motors have seen since they were first introduced, the field has been considerably modified, the armature has not been changed in the least, and it remains to-day the same as at first; it is either a plain Gramme or a Siemens armature. In the larger motors the gramme armature is employed, and in the smaller the Siemens. The same principles of construction are carried out that are employed in the manufac-

ture of armatures for dynamos. The most popular form at present is the drum type, because of its simplicity of construction, compact bulk, and the consequent small proportions of the whole appliance.

The commutator and brushes are used on direct-current motors, and are also the same as those of a continuous-current dynamo.

One of the first applications of commercial electricity in dental practice, was the use of the electric motor. This had been scarcely perfected before dentists recognized its value in their work. It was soon established in both the operating room and the laboratory, and to-day there is scarcely a well-regulated office in which electricity is available, that does not make use of one or more electric motors.

No single appliance has done so much to elevate the tone of the dental office as the introduction of the electric motor and engine. It has transformed a performance which reminds one of the scissors grinder, and one which was chiefly a physical operation, into one which partakes more of a digital and mental operation. The dentist has no longer to treadle a wheel that an engine bur may revolve, but, by the mere touching of a button, the bur is set in motion and the attention of the operator, instead of being divided between treadling a wheel and the management of the instrument in the tooth, may now be concentrated upon the latter. The body of the dentist may then be perfectly quiet, and the bur controlled with a steadiness and sensitiveness of touch that is not dulled by body vibration. In the course of time the management of the electric engine and switch-board

becomes automatic and the dentist controls these without going through the mental routine.

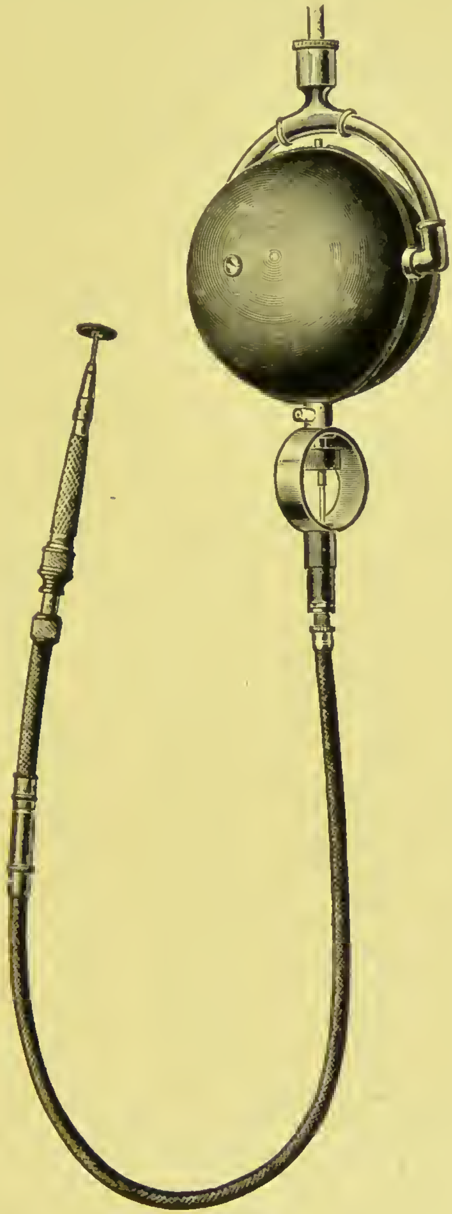

FIG. 86.—THE COLUMBIA DENTAL ENGINE.

The first electric engines made their appearance in 1885. The Griscom was attached to one end of the

White flexible arm and was suspended over the operating table. The Detroit motor was a separate fixture. From these a few years later, was evolved the Kells system of motor and engine. While new improvements were made at a very rapid rate, they were principally in the minor details. The general features of the very first engines and systems are still adhered to.

The dental engines of to-day may be classified into three groups. Those in which the motor is attached directly to the arm-piece, those in which the motor is attached to the base of the engine, and those in which the motor is placed at some distance from the engine arm and power is transmitted thereto by a long belt. The first class was represented by the Griscom, the second by the Detroit, and the third by the Kells.

The first class is found on the market to-day under the name of the Columbia engine, which is illustrated in Fig. 86. The motor part of this engine is about one-twelfth horse-power. The field is spherical in shape, and is encased in a metal cover which makes it noise and dust-proof. One end of the armature shaft is attached to a flexible arm. In making this attachment an insulating material is inserted between the motor and flexible arm, the purpose of which is to protect the patient in case of accidental grounding of the wiring of either the field or armature. If grounding were to occur and the patient were to touch the iron work of the chair to which a fountain cuspidor is attached, he would receive a severe shock. While it is not intended that the wire of the motor should touch any metal part, this sometimes accidentally occurs in the

best of motors, and the use of the insulating coupling prevents what would not be fatal, but a very unpleasant occurrence.

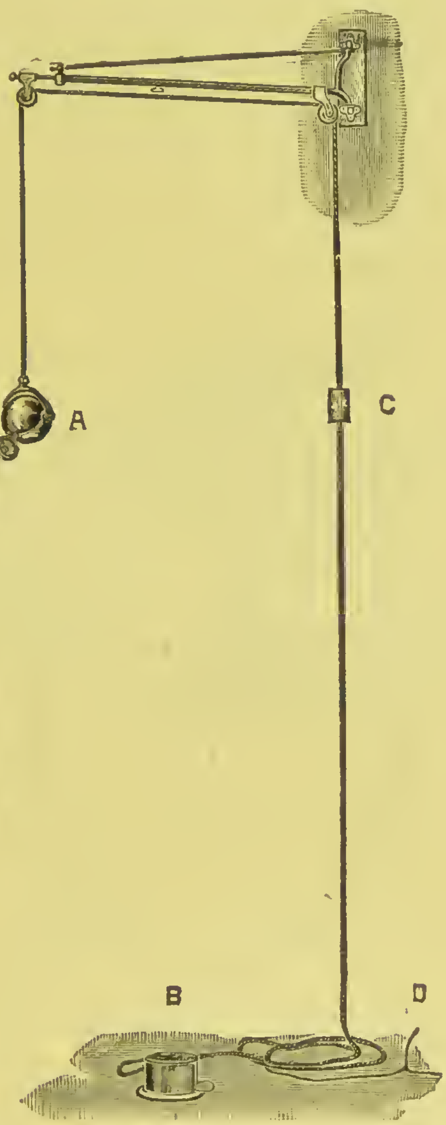

FIG. 87.—COLUMBIA ENGINE AND SUPPORT.

The motor is balanced in a swivel-like yoke, with which it is suspended. In using it the dentist has only

to sustain the weight of its flexible arm. The electrical wires which conduct the current to and from the motor serve to suspend the motor at a convenient height from the chair. These wires are bound into a single cord, which passes up to the ceiling, thence over a pulley to the wall, and then down over a second pulley where a weight equal to that of the motor is attached as diagrammatically shown in Fig. 87.

FIG. 88.—WHEELER DENTAL ENGINE.

This arrangement permits of ample and free movement of the motor in all directions.

The foot switch is unique in its construction. It is wired so as to operate the motor in either direction by pushing the lever to one side or the other. It also gives

several speeds to the motor. A feature of special importance is the absence of a destructive spark when opening the circuit. Many rheostats become more or less of a nuisance by the effect of the spark upon the first button. The destructive action causes a condition of the contact and lever that makes its manipulation uneven and un-

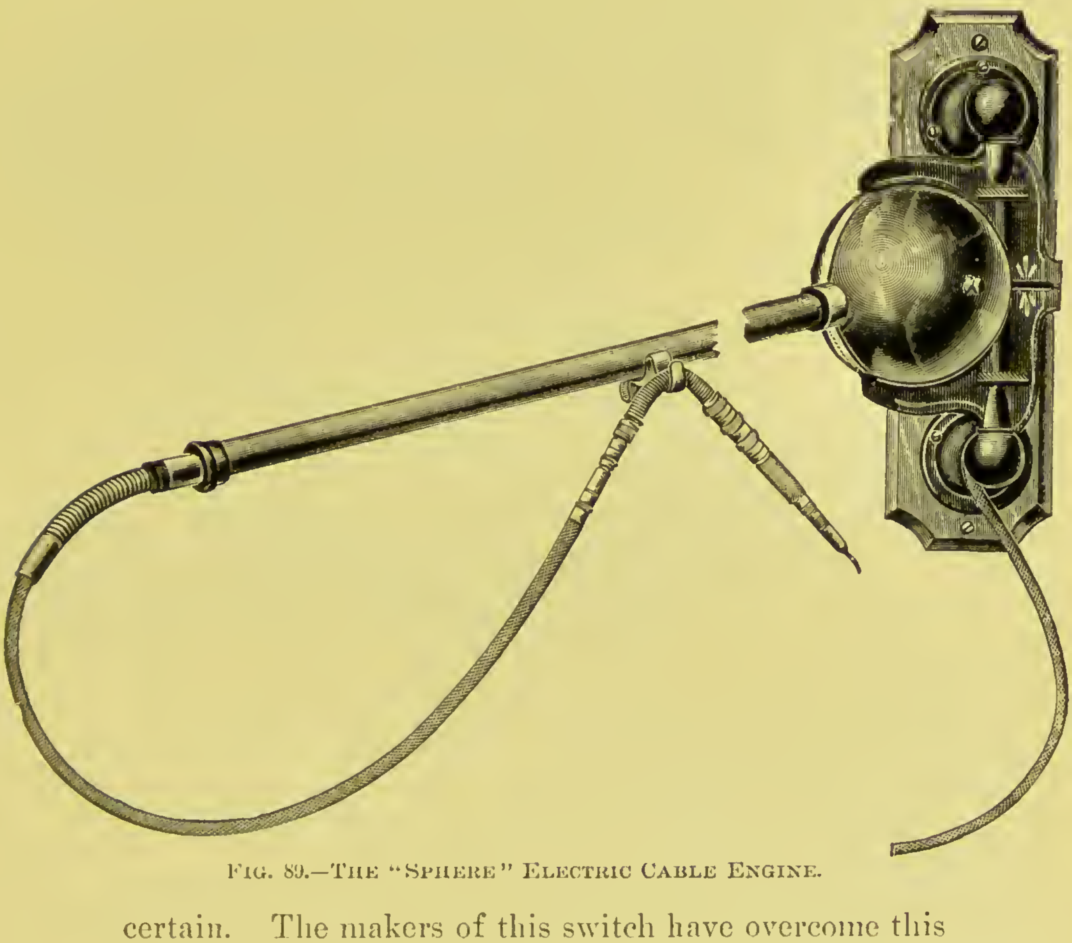

FIG. 89.—THE "SPHERE" ELECTRIC CABLE ENGINE.

certain. The makers of this switch have overcome this trouble by the introduction of a very high resistance at the last step, which cuts down the spark to such an extent as to make it negligible.

The Wheeler Dental Engine, as shown in Fig. 88, is

one of the same class as the foregoing. It differs from it, however, in that it is intended to be placed on a bracket near the chair and has not the range of position. It, however, possesses an unique feature in the method of speed regulation. One end of the armature shaft has a true disc mounted thereon. A friction wheel is

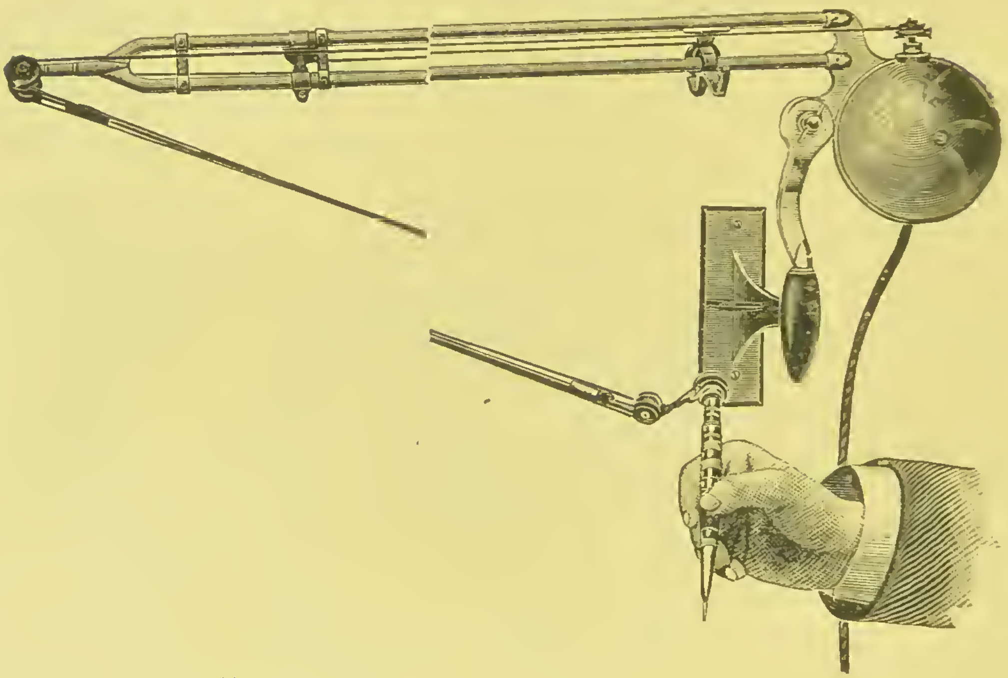

FIG. 90.—REGISTER ALL CORD ELECTRIC ENGINE.

so adjusted that it will bear upon the disc with sufficient force to be revolved thereby. This wheel takes the place of the pulley of the usual flexible dental engine arm and pulley. By the use of a lever the friction wheel can be moved back and forth on the face of the disc. In one position of the wheel the bur is rotated in a right hand direction and in the opposite position it is reversed, and between these two points any degree of speed can

be had. An automatic device in which the hand-piece is hung opens the circuit when the engine is not in use.

As another illustration of the first type of electric engines, we may take the engines made by the Electro Dental Manufacturing Company. One of these as shown in Fig. 89, has its motor pivoted in a wall bracket, and power is communicated to the hand-piece through a rod and flexible cable of about equal length.

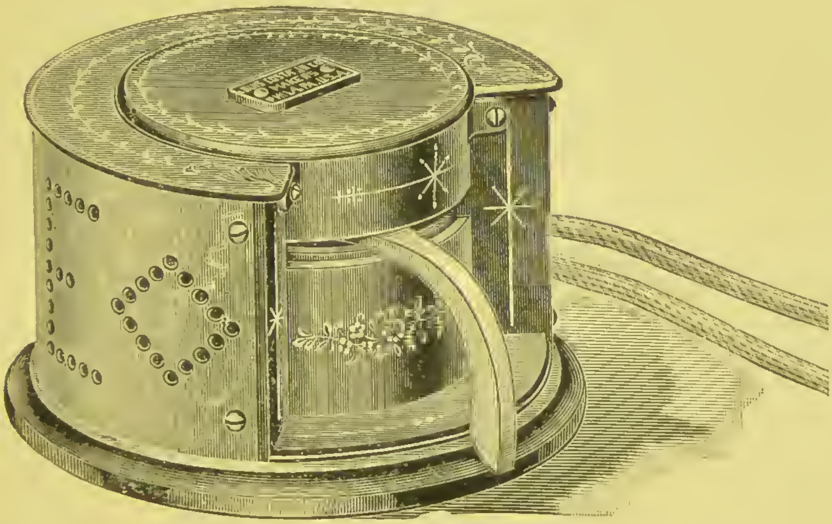

FIG. 91.—FOOT SWITCH.

The same company also has an all-cord engine mounted in a similar manner except that the motor shaft is in a perpendicular position, as shown in Fig. 90.

Both styles of engines are to be controlled in the same manner by the movable foot switch as illustrated in Fig. 91. Pushing the lever to the right increases the speed of the motor in its forward direction, and pushing the lever to the left regulates the speed in the opposite direction.

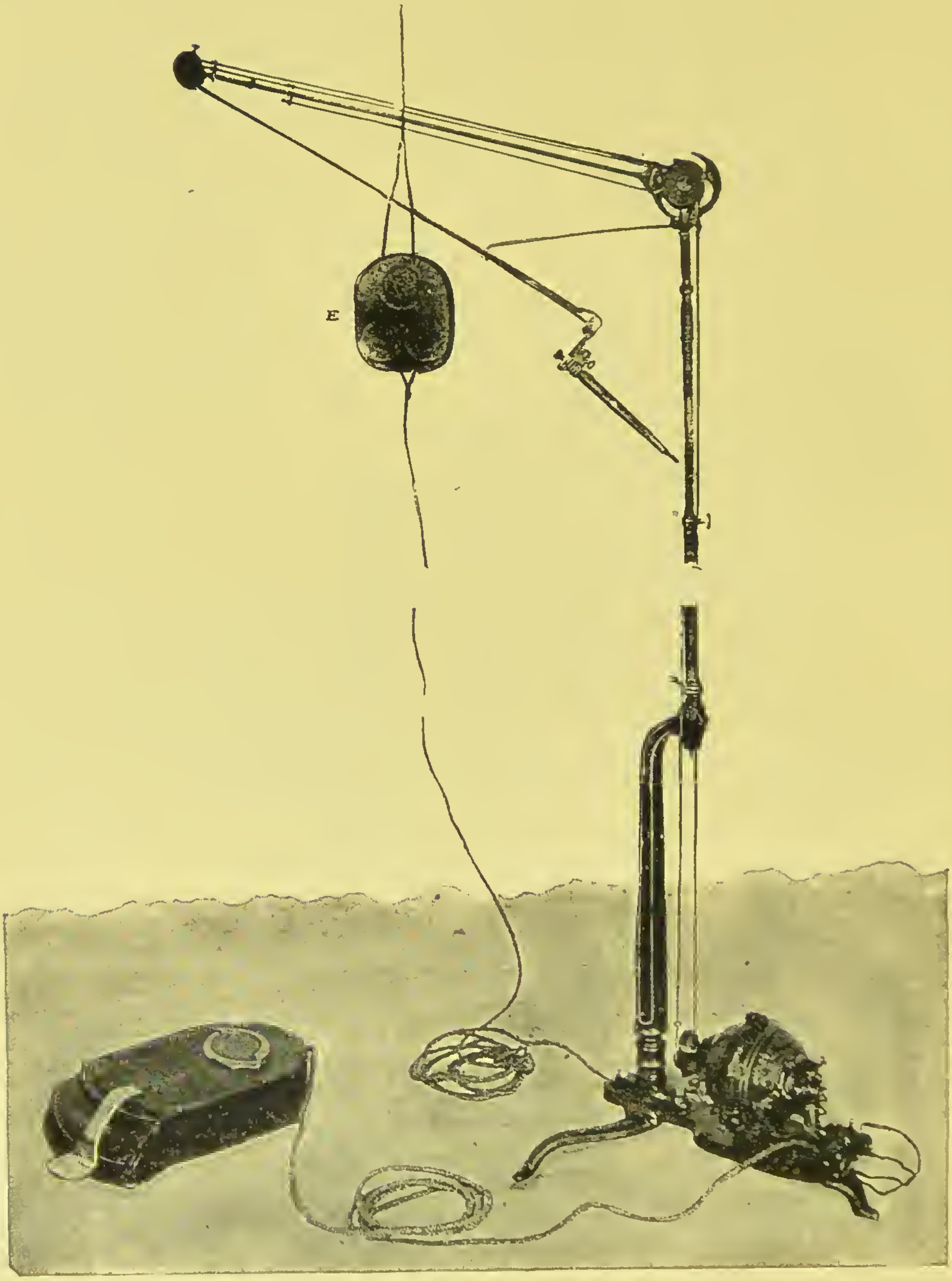

FIG. 92.—S. S. WHITE MOTOR AND ENGINE.

It gives four speeds in the forward, and two in the reverse direction. The lever may be locked at any position so that it is not necessary to keep the foot against the lever at all times. A slight touch will release the lever when it will return to the center and stop the motor.

As an illustration of a modern engine equipment of the second type we may take the S. S. White as shown in Fig. 92. In this the motor forms part of the engine base. The upper part may be a cord engine as shown or it may have the flexible arm. The engine can be moved about the chair in the same manner as a pedal engine, and except that it is somewhat heavier by reason of the motor, one who is accustomed to the old style finds little difficulty in adopting the new.

The same company has another engine upon the market in which the motor is a part of the base of the engine. This as shown in Fig. 93 is somewhat heavier, but being provided with castors can be easily moved about. The motor is encased in a glass cover which renders it noiseless and also protects it from dust. It is made to operate in either direction and at various rates of speed. It also has a unique feature in the break. A disc fixed near one end of the pulley shaft below becomes magnetic by the touching of a button on the foot switch-board. The disc thus magnetized attracts another disc which is upon the same shaft and which also serves as the pulley wheel. The adhesion of these two instantly stops the belt.

The motor is of the motor-dynamo class by which is meant that while it is operated by an electric current

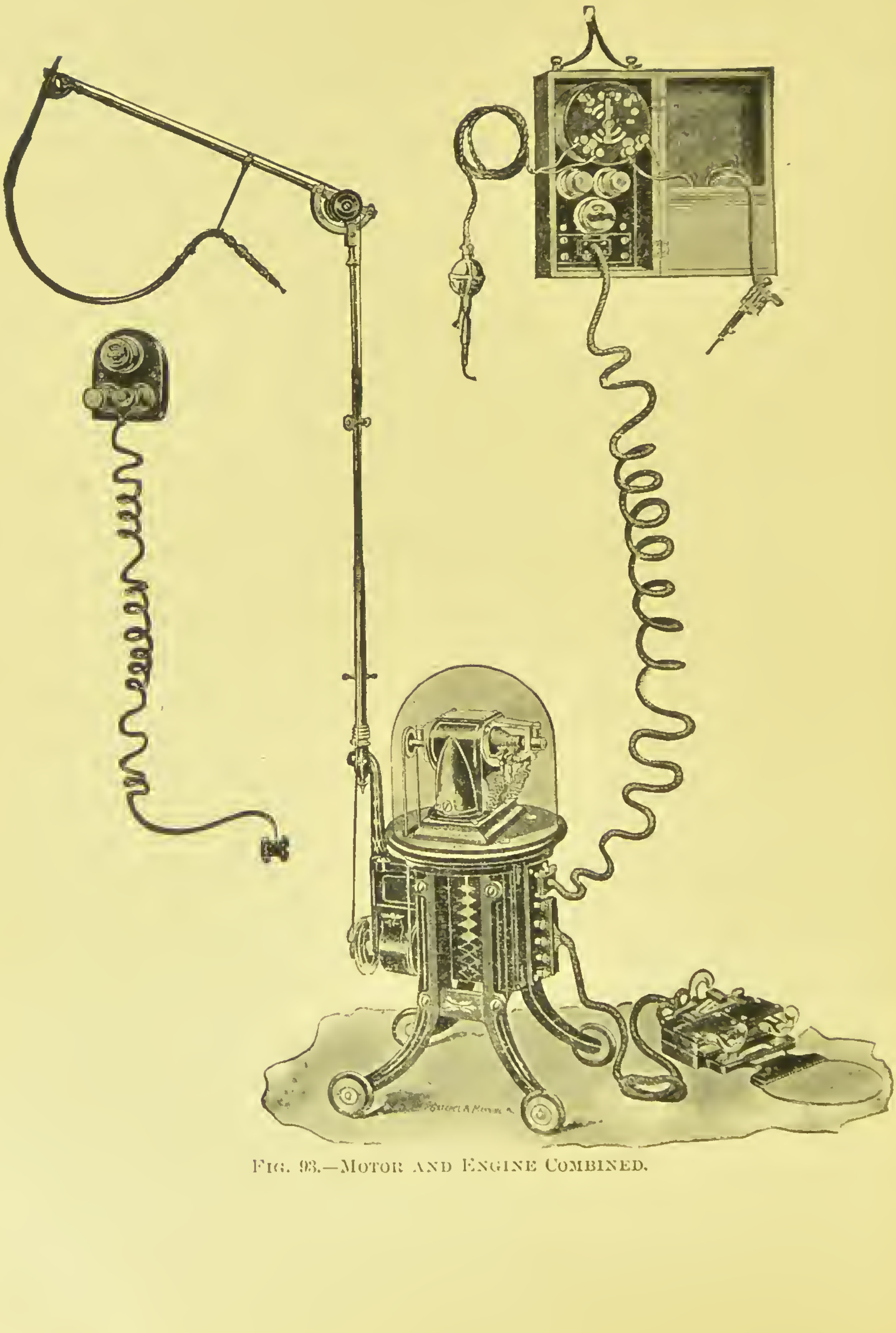

FIG. 93.—MOTOR AND ENGINE COMBINED.

on one end of the armature it will also give off another current from the other end. The current yielded by this motor-dynamo is especially intended for heating purposes, such as the root-drier, the cautery, and electric mallet which are supplied with the outfit as shown.

FIG. 94.—BERRY ENGINE.

The Berry Electric Engine illustrated in Fig. 94, is somewhat smaller than the ones just described. It, however, has the foot switch embodied in the base in such a manner as to resemble the treadle engine. This engine is one well adapted for the use of those who do

not wish to change from the conventional form of dental engines.

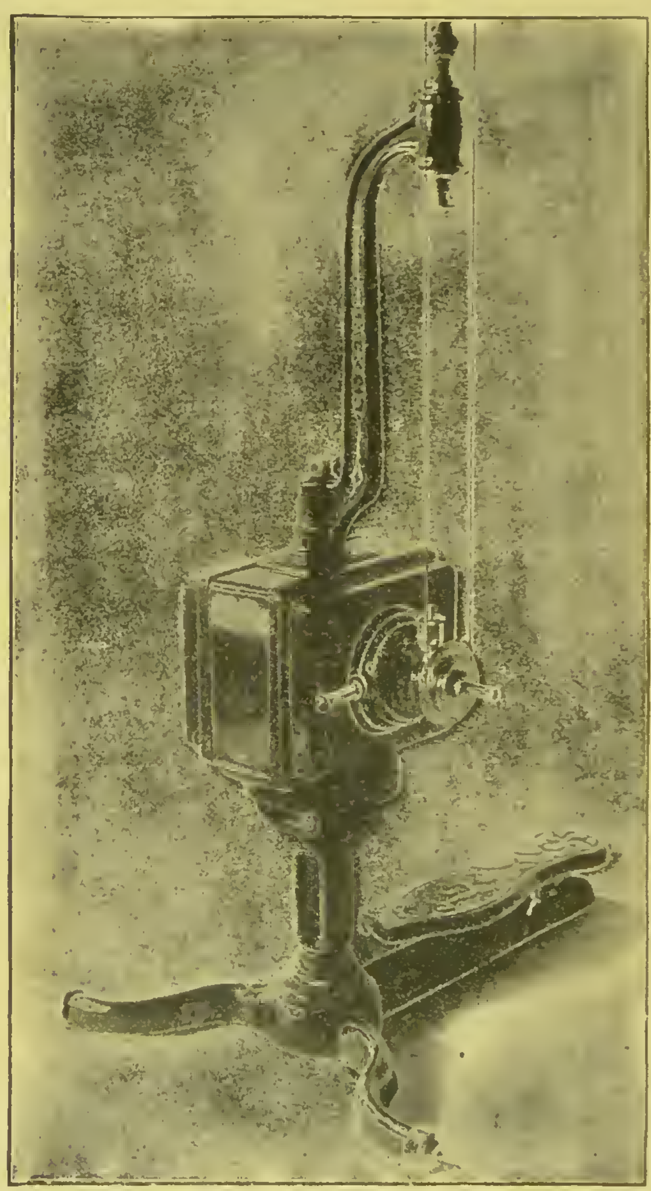

Fig. 95.—Motor and Switch of Berry Engine.

In Fig. 95 is an enlarged view of the base. It will be seen that the motor takes the place of the wheel, and

FIG. 96.—BROWNING ENGINE WITH DORIOT ARM.

the treadle operates the rheostat lever for regulating the speed of the motor. The dentist who has become ac-

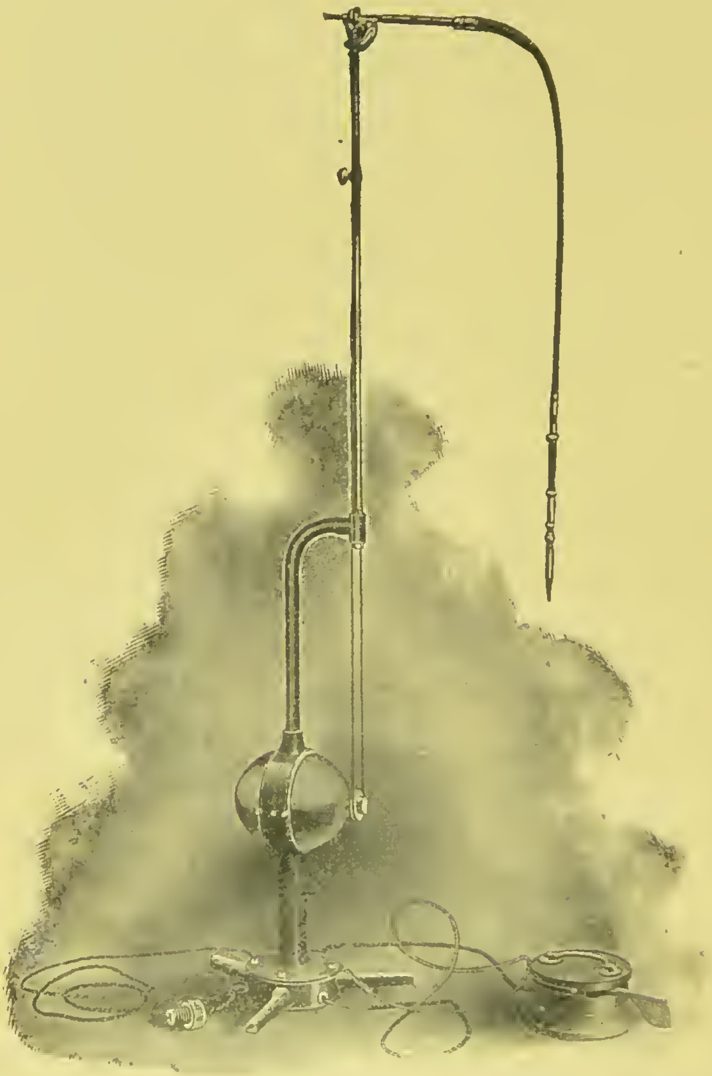

FIG. 97.—BROWNING ENGINE WITH FLEXIBLE ARM AND MOVABLE FOOT CONTROLLER.

customed to the treadle engine will very easily learn the management of such an engine as this.

The Browning engine is another of this class. Fig. 96 shows this engine with foot controller in the base. This engine, like many others of its style, may be used to operate the all-cord and Doriot arm-pieces.

The same company supplies an engine to all appearance like the foregoing except that the controlling device is separate from the engine base as shown in Fig. 97. This gives the operator more freedom of movement, enabling him to place the engine at the full cable's length from the patient and at the same time have the foot controller within easy reach. In this illustration the engine is shown with a flexible arm.

It requires but little ingenuity on the part of the dentist to convert his foot engine into one of the former style. An ordinary fan motor of one-twelfth horsepower, such as can be had upon the market at a cost of from twelve to fifteen dollars, will meet all the requirements. This should be firmly fixed on the base in such a manner that its pulley comes as nearly as possible in line with the upper pulley. If the wheel of the old engine be removed no difficulty will be experienced in doing this. The proper speed will be attained for the shaft if the pulley wheel of the motor is about the same size as that on the head of the engine.

The most difficulty will be experienced in making the rheostat for regulating and reversing his engine. To do this he should proceed as follows: Take an ordinary school slate, four by six inches, from which the frame has been removed, and wrap about thirty feet of twenty-seven gauge german-silver wire upon it. The edges of the slate can be notched so as to keep the wire in place.

Leave the two ends about six inches long, and solder another piece about the same length to a wire near the middle of the slate. This gives three wires to be connected to the switch which we will now describe. Fit

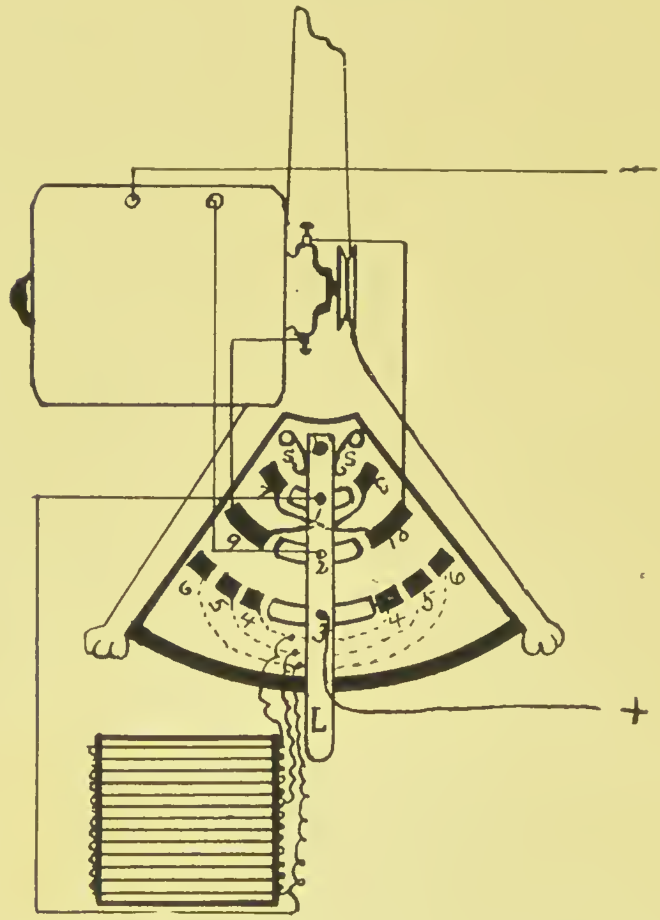

FIG. 98.—DIAGRAMMATIC WIRING FOR RHEOSTAT AND REVERSING APPLIANCE.

a triangular piece of hard fiber about three-eighths of an inch thick between the two feet of the base which will be nearest to the foot when the engine is in position for use. Pivot a fiber lever as shown at L in Fig. 98, so

that it will swing from side to side by pressure of the foot, and yet in such a manner that the springs S and S will return it to the center when the foot is removed. Fix three brass springs, 1, 2, and 3 on the under surface of this lever. These springs should be about twenty-eight gauge, one-half inch wide, and bent in the following shape, which is a full size diagrammatic section of the lever and one of the springs:

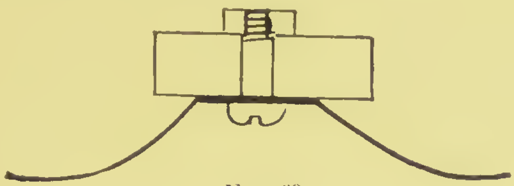

FIG. 99.

Describe upon the fiber-board three arcs, which will come under the springs, when they sweep in either direction. Fasten upon the board as represented in the diagram ten brass plates, eighteen gauge in thickness. Connect plates 4 together with a wire running underneath, and in like manner connect plates 5 and 6. Then connect in the same manner on the under surface plates 7 and 10, and on the upper surface plates 8 and 9. By so doing the wires in crossing one another cannot come in contact. The rheostat is shown in front of the switch-board for simplicity; this, however, is to be placed under the fiber-board, care being taken that its wires do not touch those of the switch-board. A sheet of mica or asbestos should intervene between the two to insure against such contact. Connect plates 9 and 10 with the two brushes of the motor; spring 1 with the end of the rheostat that is connected with plate 6;

spring 2 with one end of the field-wire of the motor; and spring 3 with one of the mains. The other main is to be connected with the other field terminal. The wires from 1, 2, and 3 should pass along the lever to its pivot and from there to the board by small coils, the flexibility of which will permit of the lateral movements of the lever.

In the practical operation of this switch, pushing the lever to the right brings the three springs in contact with three plates. The current enters plate 4 and passes through the rheostat, then through the armature and field in series. Pressing the lever further to the right till it comes in contact with plate 5, cuts out the resistance between 4 and 5, and the motor increases its speed accordingly. When the spring is on 6, all the resistance is cut out, and the full potential is operative. During these three steps there has been no change in the relations of 8 and 10. Pressing the lever to the left from the middle point, reverses the direction of the motor, and gives three speeds as before.

The speed, as just seen, is regulated by the plates 4, 5, and 6. The purpose of the other four plates is to reverse the direction of the motor. It will be seen that when spring 2, for instance, is in contact with plate 10, the current enters at the upper brush to the armature and when it is on plate 9, the current enters at the lower brush to the armature, the result of which being a reversal in the direction of the current through the armature, and the field always remaining the same, the armature reverses its direction of rotation.

An engine fitted out in this manner, although some-

what heavier than the original, is one very easy for the dentist to begin with. The manipulation of the handpiece and the flexible arm is the same as before, and he has only to learn the management of the foot-switch As a precaution against grounding any part of the wiring on the metal base of the engine and shocking the patient, a section of fiber or vulcanite should be inserted somewhere in the upper portion of the shaft which supports the flexible arm.

In taking up the third type of electric engines, or those in which the motor is situated some distance from the engine, and power is transmitted thereto by means of a belt, we find there is a large variety of them. We may first take one of the S. S. White engines. This company has supplied a line of engines of such a variety as to meet all the requirements of current, and about all the whims of operators. It furnishes dental engines of all three types, some of which have already been described, but the favorite ones are of the third type. Probably the most convenient style is that in which the flexible sleeve is pivoted upon the end of a bracket fastened to the window frame as shown in Fig. 100. The bracket is provided with an extension arm for preserving the proper tension upon the belt. The spiral spring of the first section gives a supple flexibility to the handpiece, and this is further aided by the lateral movement at its pivotal attachment to the bracket. Moreover, the pivoting of the bracket at the wall permits of its being pushed aside when not in use, as well as gives additional freedom of movement to the arm.

The motor is placed upon the floor and the usual form

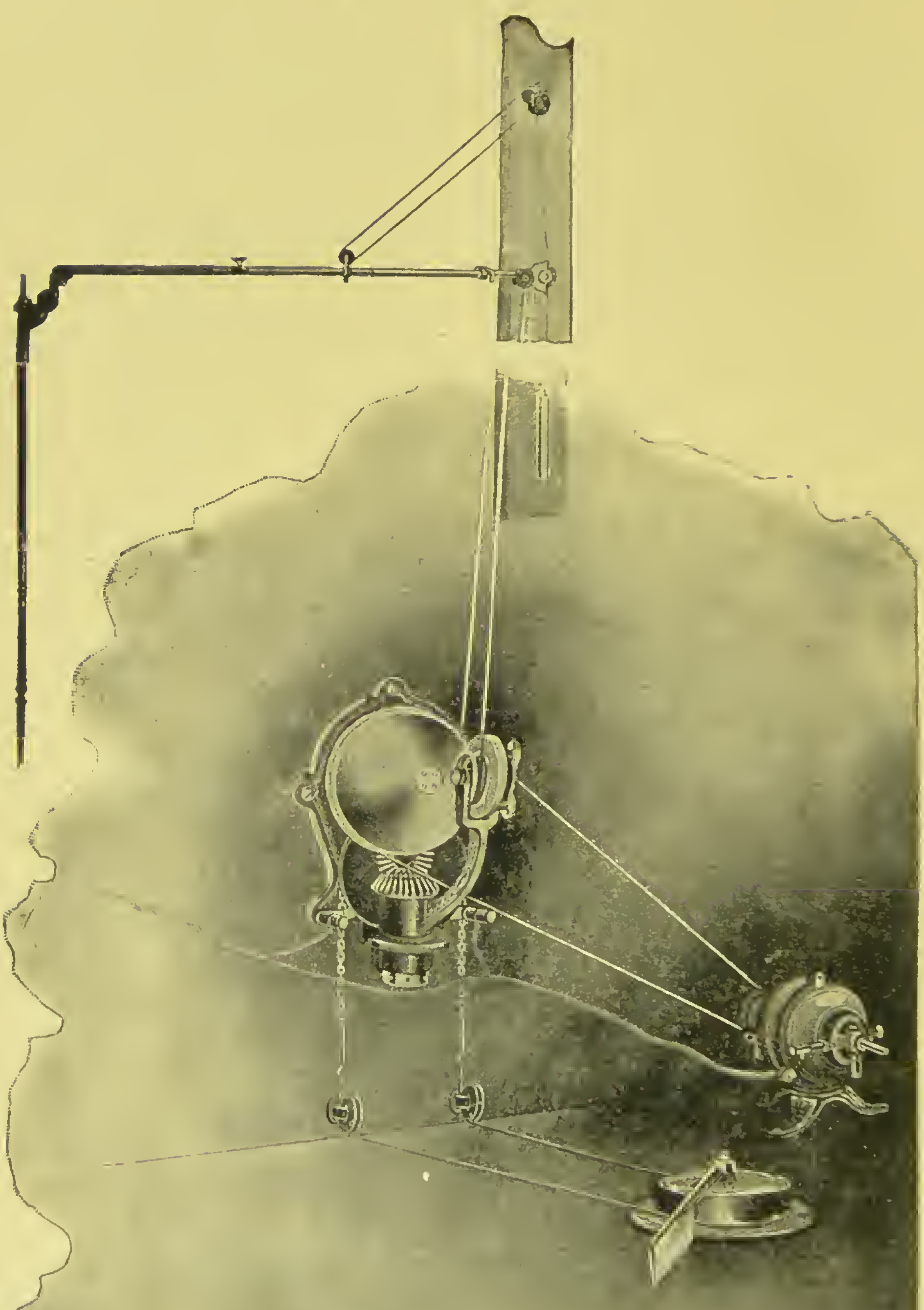

FIG. 100.—S. S. WHITE ENGINE OF THE THIRD TYPE.

of switch-board is provided, which can be placed at any convenient point about the chair.

The same company also supplies a cord engine somewhat upon this plan. Instead, however, of the movement of the arms being in a lateral direction, it is at right angles. The two arms of this engine are of about equal length. A balancing weight sustains the weight of the two, so that the operator has only to manage the hand-piece. While all cord engines have not that freedom and flexibility of movement of the hand-piece, this form of engine is quite popular because of the direct impulse given the bur by the motor. The "back-lash," as it is called, is avoided by this arrangement. The motor is usually placed upon the floor and the cord runs direct to the hand-piece without the intervention of a spiral spring.

The engine shown in Fig. 100 is one which can be operated by an alternating as well as a direct-current motor. The friction device shown in the center of the figure is intended to be operated by a motor running at a constant speed, and the variable speed for the engine is obtained by shifting the position of the small friction wheel upon the face of the larger disc. This device differs from most appliances of its kind, the disc being the shape of half a sphere and the pulley wheel being carried upon an arm which is pivoted at a point which is in line with the center of the sphere.

The foot switch of all this style of regulators is fixed at a convenient point under the chair, and motion is communicated to the movable arm by means of two wire cables. Shifting the lever to the right moves the

arm in that direction which gives the engine a forward motion, and shifting to the left reverses the direction. The speed of the bur is regulated by the distance that the friction pulley is from the center of the disc.

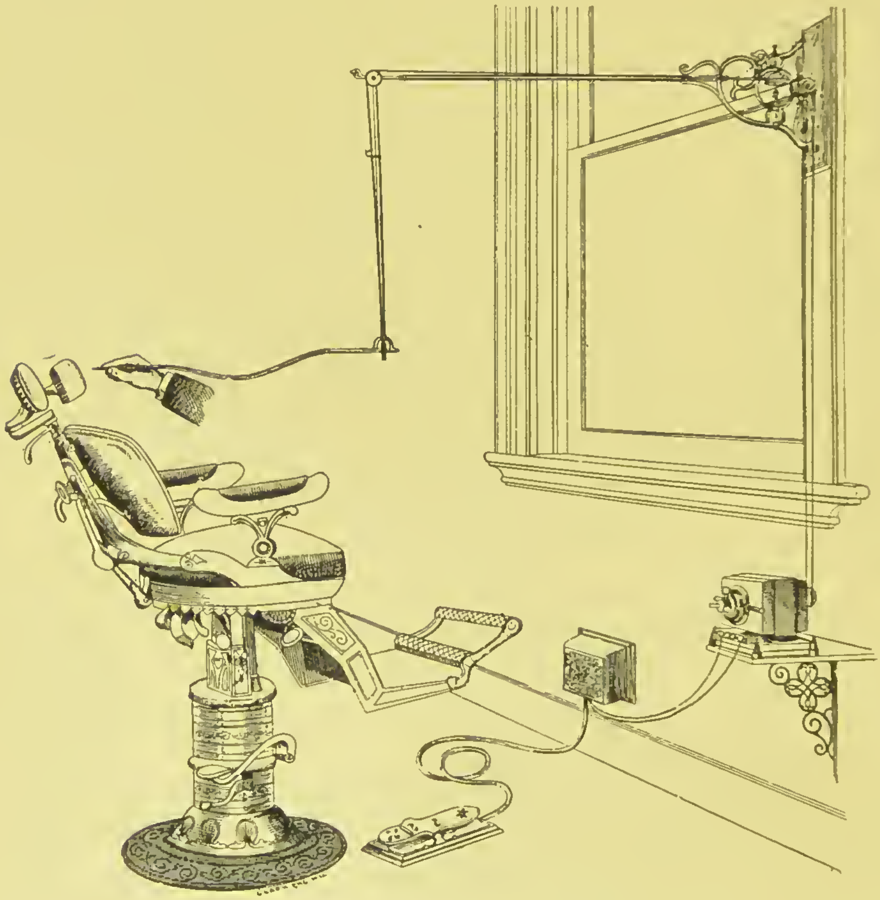

FIG. 101.—BERRY DENTAL ENGINE.

The Berry Dental Manufacturing Company also has an engine of the third class upon the market. As seen in Fig. 101 the arm is fastened to the window frame and is of the proper length to reach the chair. The motor is stationed below. The foot switch only contains the con-

tact buttons for the regulating resistance which is upon the wall. By this arrangement the switch can be made much lighter than one which also contains the resistance.

An engine devised by Dr. W. H. Taggart in 1887, in point of simplicity and effectiveness, and one which may be said to be a compromise between the flexible arm and the cord engine deserves mention, and the author having used one made upon these lines since that time, can speak from the standpoint of experience. If the

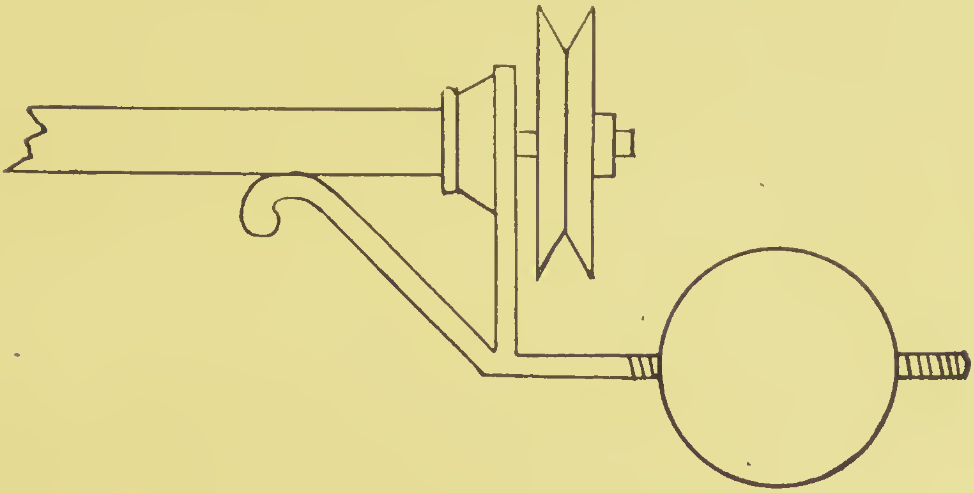

FIG. 102.—BALANCING HEAD OF TAGGART ENGINE.

arm of the Shaw engine be removed from the upright, and an L-shaped piece be soldered below the pulley, as illustrated in Fig. 102, and a ball of metal about two inches in diameter be drilled and tapped so as to screw on the arm, the engine is complete. The motor should be an eighth or twelfth horse-power. This can be stationed anywhere about the office. If the dentist wishes to be economical, this motor can be used in the laboratory for running the

lathe also, and the belt run from this out to the chair. Two pulleys of hard rubber, such as are used on the S. S. White cord engine, should be mounted on a rosette of wood, about five inches apart, and this rosette fastened to the ceiling at a point directly over the right arm-piece of the chair. A belt of fishing line or a good grade of corset twine is brought from the motor through the two pulleys and down to the pulley of our dental

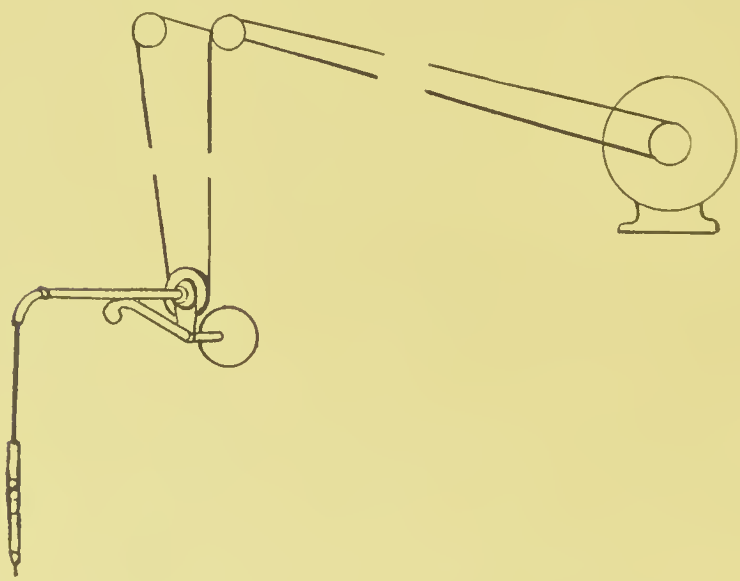

Fig. 103.—The Taggart Electric Engine.

arm. The rosette is turned at such an angle that when the engine hangs at rest it will be out of the way of the operator. After the foot switch made on the lines previously described for the base of an old engine, has been connected, our engine is complete, and such an outfit is shown in Fig. 103.

This engine has several desirable features. It has all the flexibility of others by reason of the two short

flexible springs, one at the hand-piece and one in the arm, and the universal joint at the pulley. It has but little "back-lash" because of the short length of the spiral spring in the shaft line. By screwing the weight backward or forward, the hand-piece can be so exactly balanced that the operator has no weight to handle. A hook near by holds the arm out of the way when not in use.

If the dentist wishes to perfect this in detail, so as to use the one motor for both purposes without changing

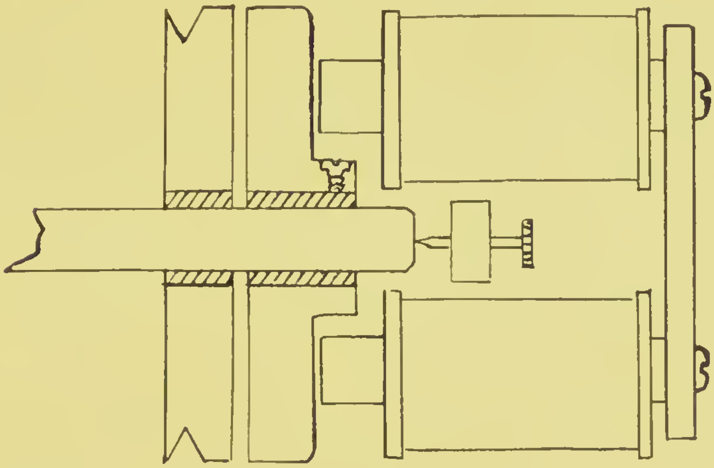

FIG. 101.—ELECTRIC CLUTCH.

the belt, a magnetic pulley on either end of the shaft, one for the lathe and one for the engine, can be automatically clutched by the mere operation of the switch for whichever instrument he is using. The electromagnets for this purpose should be wound with the same size of wire as the field of the motor, and placed in series with it. They should be about one inch in diameter, and two inches in length, and poised as close as possible to the back of a soft iron disc on the end of the shaft. This

disc should be electrically insulated from the shaft by a bushing of fiber and yet firmly fixed thereto. It should, moreover, be turned perfectly true on both surfaces after being mounted. Just inside of this disc toward the motor is a loose pulley of soft iron with a fiber bushing

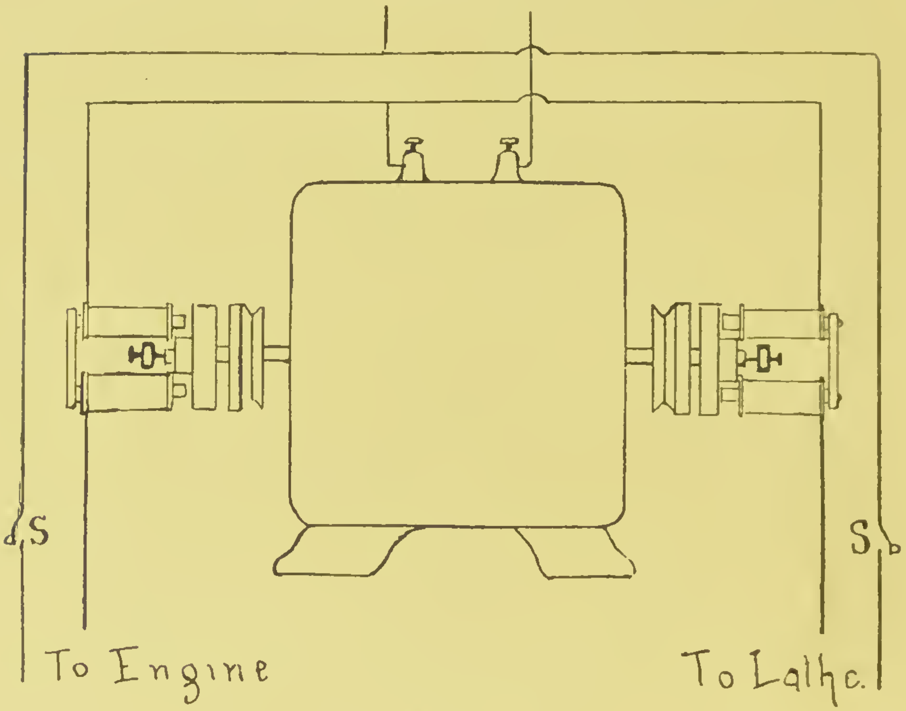

Fig. 105.

which insulates it from the shaft as sectionally shown in Fig. 104, which represents one end of the armature shaft.

When the magnet is energized it induces magnetism in the fixed disc at the end of the shaft. This, in turn, attracts the loose pulley to it so firmly that it becomes a fixed pulley for the time being, or as long as the current is supplied to the motor through the electromagnet at this end.

A needle pointed set-screw makes accurate adjustment of the shaft, and also receives the end-thrust produced by the magnetic pull.

The other end of the shaft is to be precisely the same, and the wiring must be so made that when using the switch-board the pulley wheel for that side only is affected. This may be done in the manner illustrated in Fig. 105.

In this diagram S represents the foot-switch in the operating room and also the switch in the laboratory.

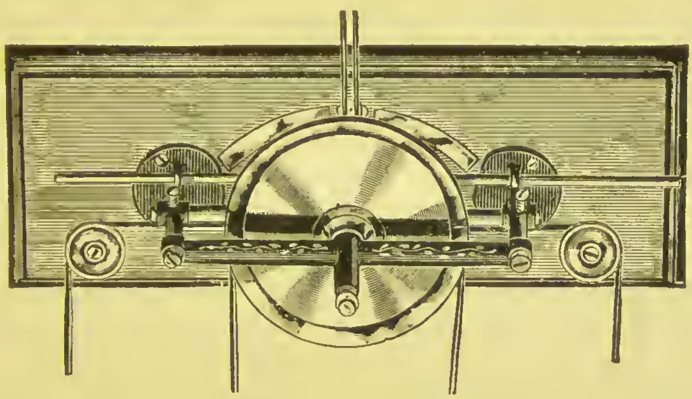

FIG. 106.—MASON SPEED REGULATOR.

The Mason engine was one of the first mechanical appliances for obtaining a variable speed from a motor running at a uniform speed. This device which is shown in Fig. 106 consists of a large disc which may be operated by any electric motor. For this reason the Mason system has been of especial value where only the alternating current can be had. A friction wheel which also serves as the pulley wheel for the belt is mounted upon a shaft which plays back and forth in front of the disc. In either extreme right or left position the speed

is the highest and this gradually decreases as the friction wheel approaches the center where it comes to

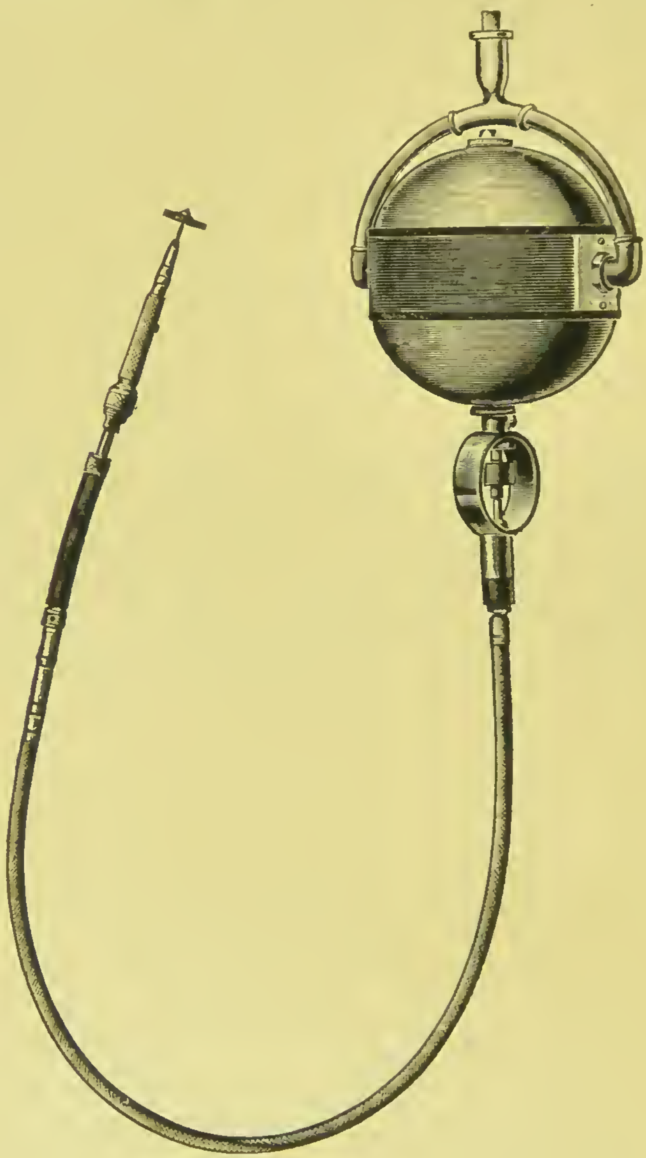

FIG. 107.—RITTER ENGINE FOR ALTERNATING CURRENT.

a full stop. It then reverses its direction when passing to the other side of the disc. In this simple manner

the operator, by using a lever under the chair, has complete control over the speed of the engine as well as the direction of rotation. The appliance is also provided

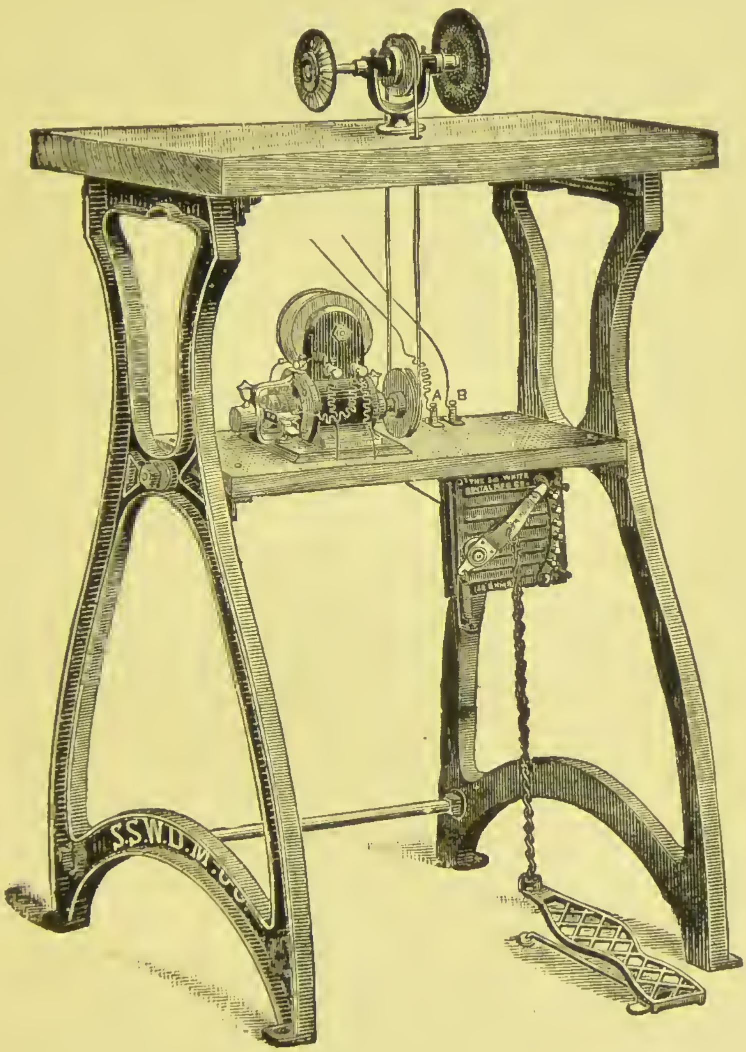

Fig. 108.—Motor and Lathe Head.

with a switch which automatically opens the circuit when the lever is in the middle position and closes it when the lever leaves the center.

All the foregoing engines except the one in Fig. 100 and the Mason engine are to be operated by the direct current. Up to the year 1899 there was no dental motor that could be satisfactorily operated upon the alternating current. In that year the Ritter Dental Company brought out a motor for this current which

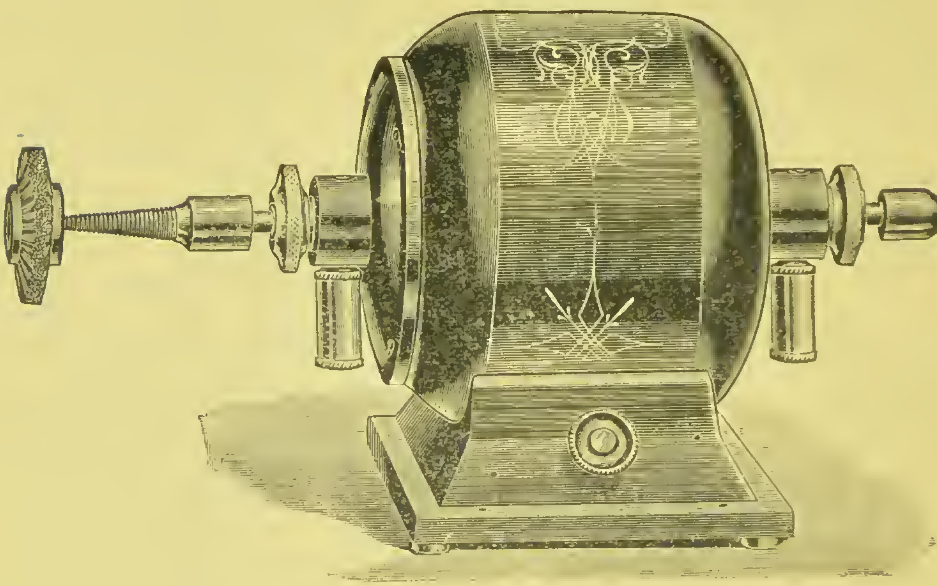

FIG. 109.—RITTER ELECTRIC LATHE.

can be controlled, and which is in nearly every respect equal to the direct current motor. This as shown in Fig. 107 differs but little in appearance from the direct-current engine of Fig. 86.

THE ELECTRIC LATHE.

Closely following the introduction of the electric motor in the operating room, it was adapted for laboratory use. One of the first for this purpose is shown in Fig. 108. This was a most natural transition. It made use of the lathe heads then in use, and simply

FIG. 110.—ARMATURE AND BEARINGS OF RITTER LATHE MOTOR.

supplied motive power for what had before required considerable physical effort.

Although but a few years have passed there have been a great many changes in the design and construction of motors for this purpose. The most important change was the construction of a motor and lathe head in one instrument by the Ritter Dental Company. The base of the lathe is made broad enough to stand and be operated wherever it is placed. This instrument was an innovation and an ornament to the laboratory,

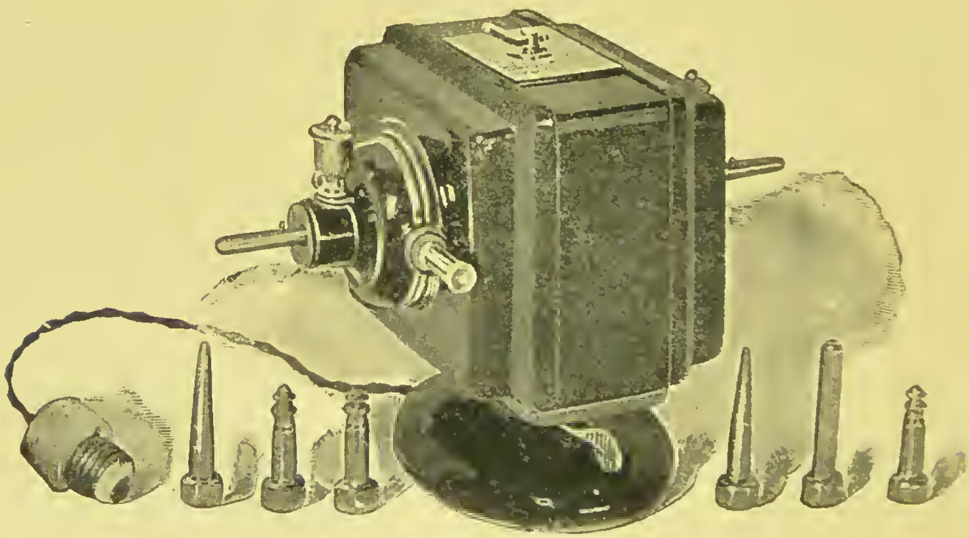

FIG. 111.—BERRY ELECTRIC LATHE.

and is so easily portable that many dentists use one motor in both departments. It is shown in Fig. 109. The field is of laminated iron and is so heavy that when a motor is assembled it will remain perfectly quiet while running. The armature is entirely enclosed, thus making it dust-proof and both ends of it are fitted to receive the chucks and mandrels. The oil is fed by means of a wick from a cup below each bearing.

A special feature of this motor is the provision for wear. A steel sleeve, shown at E in Fig. 110, fits upon the armature shaft and is readily replaced by a new one when worn to any appreciable extent. This practically makes this instrument one which cannot be worn out in years.

A switch button in front regulates the speed of the motor to suit the operator.

The Berry Company makes a lathe motor as shown in Fig. 111. This is somewhat smaller than the one just

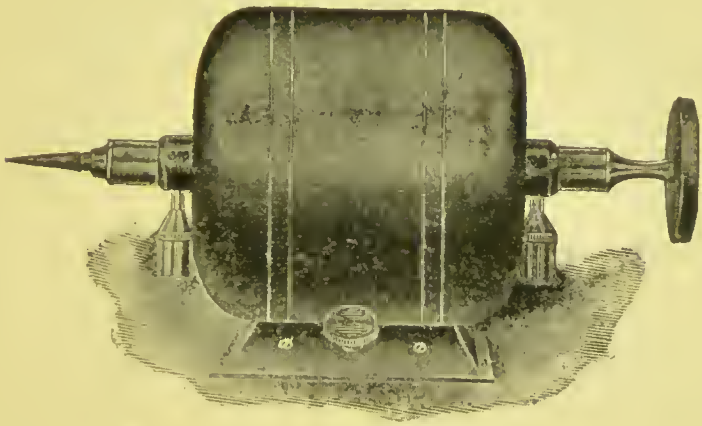

Fig. 112.--Browning Electric Lathe.

described, but is operated in the same manner. It is thoroughly made and is an ornament to the dental office.

Both ends of the armature shaft are fitted to receive mandrels. These slip on and lock themselves by a half turn in an opposite direction to that in which the armature revolves. The whole motor is dust-proof, as these motors should be. On the top is a switch for regulating the speed.

The Browning Electric Company also has a lathe motor upon the market. This as shown in Fig. 112 is

similar to the first mentioned in external appearance. It differs from it in point of finish and the method of attaching the mandrels.

The Victor Electric Company manufactures an elec-

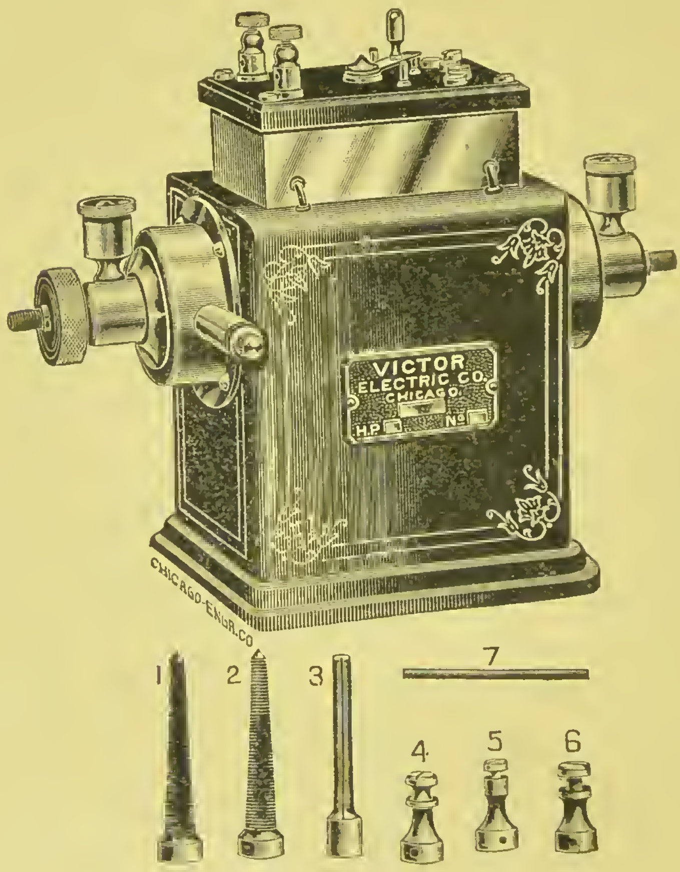

FIG. 113.—VICTOR ELECTRIC LATHE.

tric lathe which is shown in Fig. 113. This has the field below and the rheostat above. It has five speeds and is entirely closed so as to be dust-proof. The mandrels screw directly on the armature shaft by a few turns. This electric lathe is a nominal eighth horse-

power, as are also nearly all which are designed for this purpose.

Still another electric lathe is illustrated in Fig. 114. An interesting feature of this lathe is the manner of fastening the mandrels. They fit on the end of the armature shaft by an accurate taper, and are loosened therefrom by a sharp tap of the lever as seen on the right. This motor, like most of the same class, is shunt

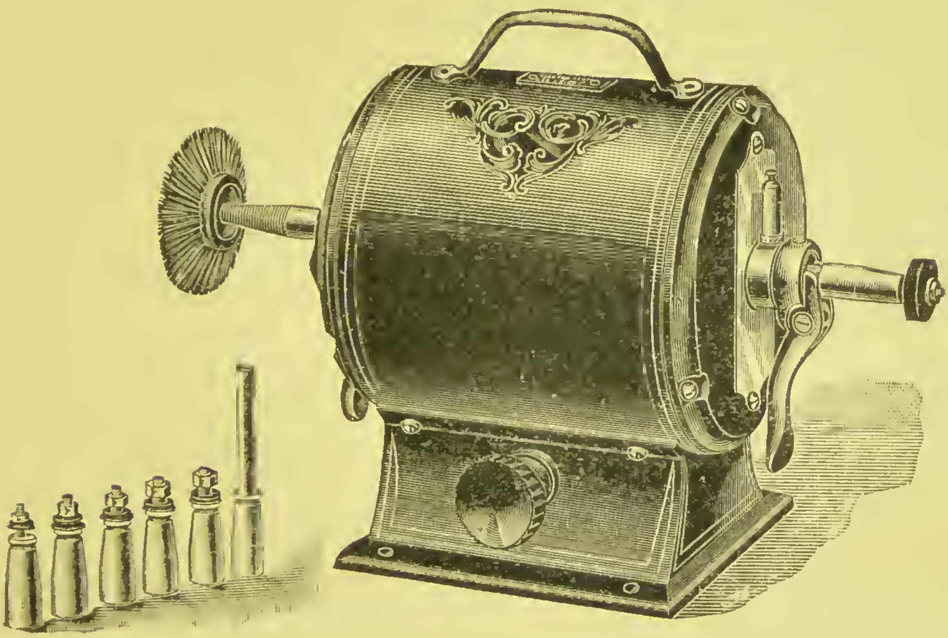

FIG. 114.—ELECTRO DENTAL ELECTRIC LATHE.

wound whereby a constant speed is maintained regardless of the load that is put upon it.

Many of the more fully equipped dental laboratories have a machinist's lathe. Even the smallest of these lathes require considerable physical strength to operate them, and it is not practical to even attempt operating the second or third of the smaller sizes by foot-power.

Here the value of an electric motor comes into play, and it will not require as large a one as might be supposed. A Number 4½ Barnes lathe, or any of the smaller sizes of machine lathes can be operated with a one-sixth horse-power motor. This size is ample for the above-mentioned lathe, and with this as an example, the dentist can readily estimate the size of motor that will be necessary for larger lathes.

The motor should be placed on a bracket back of the lathe head, and no more than a foot distant there-

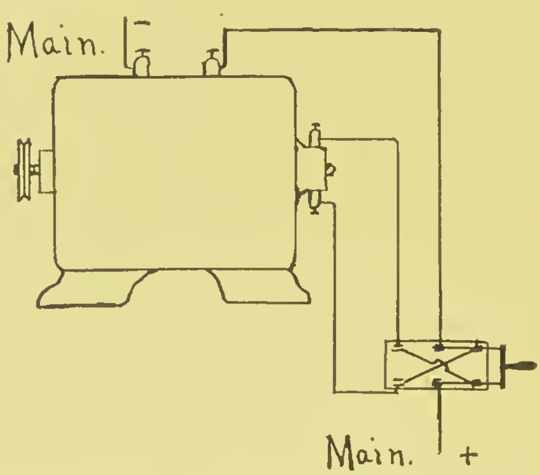

FIG. 115.—REVERSING SWITCH FOR SERIES-WOUND MOTOR.

from. It is a good plan to fasten a shelf about eighteen inches wide to the back of the lathe bed for the tools, and set the motor on this. The motor should slide upon its base, for the purpose of tightening the belt. It should also be placed with its pulley wheel to the right in order that it may not interfere with the lathe work. It will be found that if the pulley is put in line with the large end of the lathe pulley and belted thereto,

the speed of the lathe will be fast enough. Here comes in play the special fitness of individual motors for lathe work. In machine-shops it is necessary to shift the belt upon the cone-pulley of the lathe in order to increase or reduce its speed. This is quite unnecessary when an individual motor is used to operate the lathe. The rheostat not only does this but it gives a greater range of speed than can be obtained from any other source. Moreover, by the use of a reversing switch, the lathe

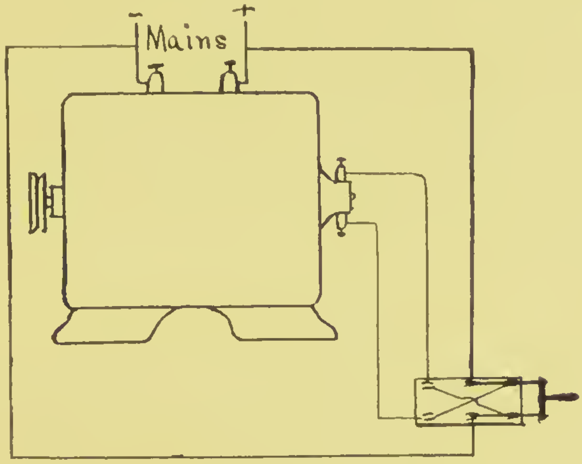

FIG. 116.—REVERSING SWITCH FOR SHUNT-WOUND MOTOR.

can be made to run in either direction, a feature not usually found in machine shops except on special lathes.

It is a good plan always to have the first button of a rheostat blank, as by so doing the rheostat also answers for a switch. The operator knows what speed he will require for the work in hand and the lever is put upon that button at once.

If the motor is not provided with a reversing switch, one can be made in the following manner: A double-

pole, double-throw, baby-knife switch can be had at any electrical supply house. This should be mounted at any convenient place. If the motor is near the lathe-head as suggested, it should be fixed on top of the motor. It should be connected to the motor wires in the manner illustrated in Fig. 115, if a series-wound motor, as in Fig. 116 if a shunt-wound motor. When the lever is thrown to the right the current is caused to flow through the armature in one direction, and when the lever is thrown to the left, it flows in an opposite direction, the effect of which is to reverse the direction of rotation.

It will be noticed that before using the switch two wires should be crossed and connected to the four corner-posts as represented. They should be placed underneath and insulated from one another and from the motor.

THE ELECTRIC FAN.

The electric fan is a welcome adjunct to the dental office, and its value is so apparent that its merits need not be elaborated upon.

Experience, however, has shown that not any fan will answer for the chair. It should be of the buzz-fan type as shown in Fig. 117. Many dentists make the mistake of using a small fan at a very high rate of speed. Such a fan to be effective creates a great deal of noise, and sends out a stiff breeze of rather small field. This is not the most desirable. All that is necessary for the comfort of both patient and operator is a gentle breeze of a wide field. The noise of the small fan, although in a measure one which is soon unnoticed, keeps one in

a semi-nervous tension. The proper fan for the dental chair would be one at least fifteen inches in diameter and an eighteen-inch fan would be ideal. It should be operated at such a speed that there will be absolutely no noise. This will usually give a gentle breeze which

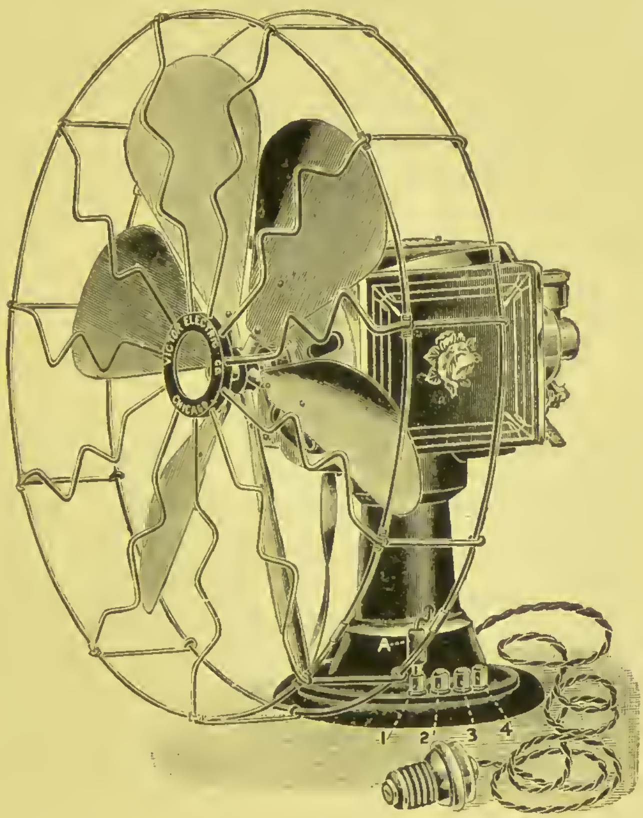

FIG. 117.—ELECTRIC FAN.

will not in the course of the operation endanger one's health, and yet keep both operator and patient perfectly comfortable. If the dentist will buy a nominal twelve-inch fan motor, and use an eighteen-inch fan thereon, he will have the ideal fan for the dental chair. The motor, in driving the eighteen-inch fan, may become

a little warmer than was intended, but it will not become dangerously so. The motor will have power enough to operate the fan at the speed indicated above and frequently a margin to spare. This can be regulated to suit the operator by means of the rheostat which is usually enclosed in the base of the fan.

THE ELECTRIC AIR COMPRESSOR.

The use of compressed air has become a necessity in the well-regulated dental office. There are several operations at the chair which can be better performed by air which comes direct from a cylinder under uniform

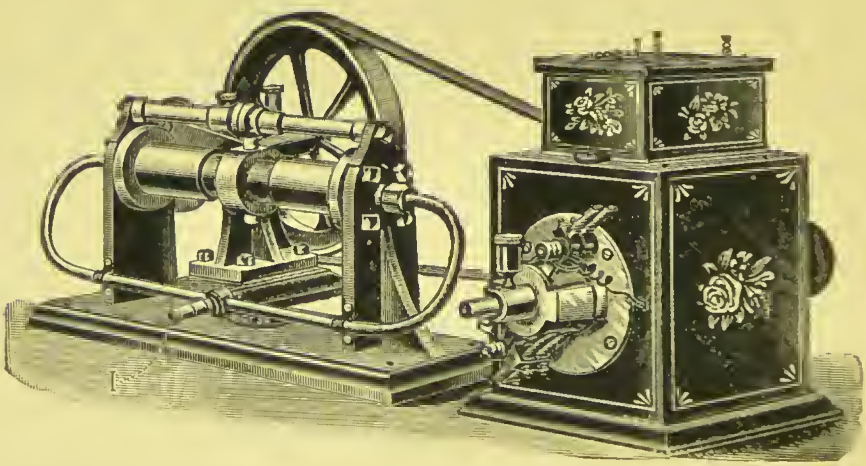

FIG. 118.—VICTOR AIR COMPRESSOR NO. 1.

pressure, than by the use of the chip-blower. The dessication of dentine, the drying of roots for filling and for setting crowns, the exploration for tartar, and for use with the atomizer require a uniform and frequently a high pressure of air. This can only be had from a cylinder of compressed air. Moreover its utility often

depends largely upon its being ready for use at any moment.

Compressed air has usually been obtained where running water is in the building, by the use of a beer pump. In offices in very high buildings, however, the pressure is not sufficient, and in suburban situations water pres-

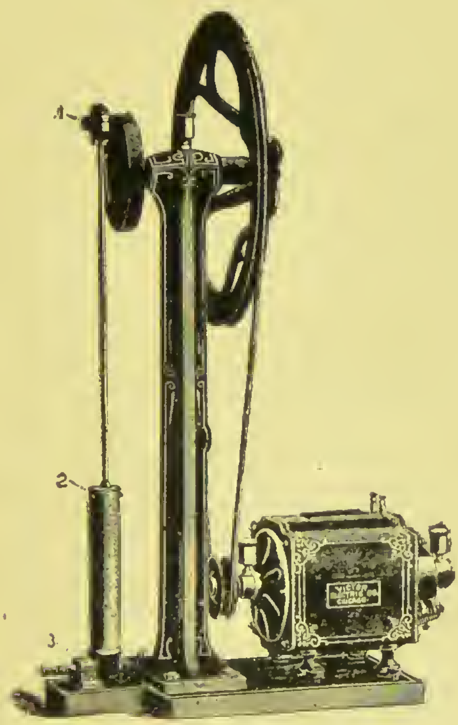

FIG. 119—VICTOR AIR COMPRESSOR NO. 2.

sure is not to be had at all. To meet these conditions the Victor air compressor as illustrated in Fig. 118 has been devised. This consists of an electric motor and an air-pump mounted together. In connection with this, a kitchen tank of at least sixty gallons' capacity should be used as a reservoir. It is not practical to operate the pump every time air is needed; moreover some blow-

pipe operations require a larger volume of air than the pump can supply. By the use of the reservoir, however, the stored-up supply, in addition to the feeding in by pumps will be sufficient to meet all the requirements.

The same company also supplies an air compressor of an upright type as shown in Fig. 119. This pump is a single-acting machine and will maintain a pressure of sixty pounds in the reservoir.

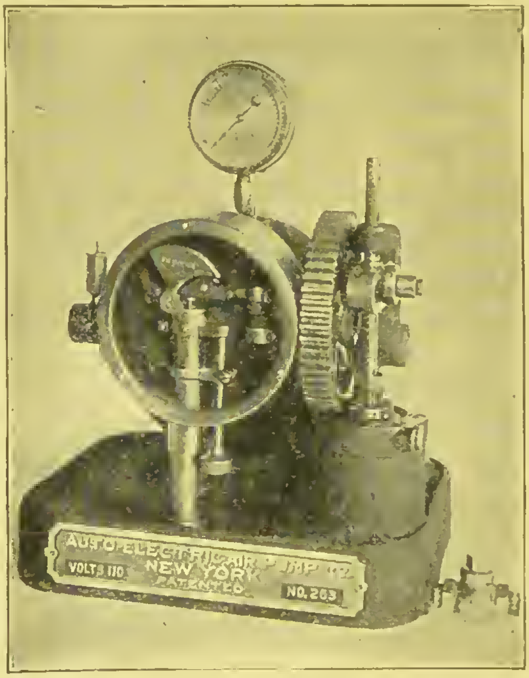

FIG. 120.—AUTO-ELECTRIC AIR COMPRESSOR.

The Auto-Electric Air Compressor takes its name from the automatic working of the device. An electric motor is directly geared to a short-stroke pump. This furnishes an air pressure of forty-five pounds. The unique feature of the appliance is the use of an electric device whereby the motor is automatically operated by

a slight variation in the air pressure. The controlling device can be set so as to operate at any desired pressure up to forty-five pounds.

In the practical operation of the air-pump, unless it is of the automatic type, it is necessary to run the motor each morning for the day's supply. The ingenious dentist, however, can easily construct a device for automatically operating any electric motor in a manner similar to the Auto Air Compressor by the lowering of the air pressure in the tank. This can be done by using a cylinder about three inches in diameter covered with a top of corrugated german silver about thirty-two gauge. This acts as a diaphram which moves up and down with the air pressure. A spring-controlled lever bears upon the center of the diaphram, and this lever is so connected that it closes the electric circuit and starts the motor when the pressure falls to a certain point. As the diaphram rises under the increased pressure, the lever is carried away from the contact, breaking the electric circuit when the air pressure reaches the desired point. In this manner the whole outfit can be made automatic, and the cut-out can be so closely adjusted by means of a screw, as is the author's, that a difference of but one pound will start the motor.

THE ELECTRIC MALLET.

All the foregoing manifestations of power are due to the motive power of an electric motor, in which the central figure is an electromagnet, the field of the motor, which causes another electromagnet, the armature, to revolve. We now take up another electrical instrument

in dental practice under the head of power; namely, the electric mallet. In this instrument we have practically the same principles at work as in the electric motor, the only difference being that the armature is given a vibratory instead of a rotary motion. The armature in some electric mallets, instead of being an electro-armature, by which is meant one whose magnetism is induced by a coil of wire carrying current around it, is a soft iron armature. An electromagnetic armature may be used for this purpose, but the requirements are not so great but that the simple soft iron armature answers the purpose in most electric mallets.

The invention of the electric mallet by Dr. W. G. A. Bonwill in 1867 may be said to mark the beginning of the use of electricity in dentistry. The electric current had been employed with questionable results for anæsthetic purposes prior to this time, but it was this instrument which introduced electricity in a practical and useful form to the dentist.

The electric mallet has properties not possessed by any other mallet. The blow, which can be regulated for any intensity, is practically the same as long as desired. A filling made in this way is more homogeneous than that produced by any other method. The automatic mallet, while similar to the electric, in some respects, gives a blow which is easily modified by the hand either by a little side pressure on the instrument, or by following up the blow with hand pressure, as one is likely to do when using this form of mallet. The same may be said of the electric mallet to a certain extent, but if the plugger is handled so as to simply play over the sur-

face of the gold, as it is possible to do, and the electro-mallet is allowed to do its work, the filling will be of the same density throughout.

A second feature of the electric mallet is the rapidity of its blows. Gold can be condensed by one heavy blow, and it can be just as well condensed by a number of light blows. The blow of the electric mallet is ordinarily much lighter than from a hand mallet. For this reason the electric mallet can be used upon thin walls which would not withstand the average blow from a hand-mallet. Moreover, the blows following so rapidly in succession, the plugger point may be moved about over the surface much as one would use a pencil, with the assurance that the area covered by it will receive several blows while so covered. It is unnecessary to set the plugger down by a direct effort unless special attention is given to a certain point. The speed of the electric mallet in condensing gold is due to the rapidity of its blows. In large fillings which are easily accessible the electric mallet in a skillful hand will condense the gold as rapidly as the assistant can place it in position. The wonderful operations of Marshall Webb were due to the electric mallet in a skilled hand.

Some people cannot withstand the blow of a hand mallet, especially if the tooth is somewhat sensitive to pressure. The electric mallet can be frequently used in these cases to advantage. It should not be understood by this that the electric mallet is without pain, but the peculiarity of its blow is quite acceptable to some people and disagreeable to others. Generally, however,

the electric mallet can be used with less pain on teeth sore to the touch than the hand mallet.

The electric mallet is not one which has a universal application, but one which is especially useful in large and accessible cavities. When used in these instances by a skillful hand, it will shorten the time at least one-third, and at the same time give a very dense and even surface for finishing. Such a surface will be without pits and will retain a high polish.

The first electric mallet as above referred to is shown in Fig. 121. This consists of a hollow handle to the upper end of which is stationed a pair of electro-magnets. The armature upon the top is of soft iron and weighted at its vibrating end. The handle is of vulcanite and is made hollow its entire length to receive the plugger. This differs from mechanical mallets in that the plugger handle and point complete is received in the rubber handle so that the same plugger may also be used with the hand mallet. The plugger used in the electric mallet has a constriction near the point which, when the plugger is slipped in the vulcanite handle, receives two diametrically opposite springs. These springs hold the plugger in the handle, and at the same time permit of slight movement upon impact of the armature. The length of the handle is so precise that when the armature is attracted by the magnets, it moves but one-eighth of an inch at its free end to deliver its blow upon the plugger joint, and yet, in the latter part of this movement, and when about to strike the plugger, it automatically breaks the current. An inspection of the mallet will show that it is

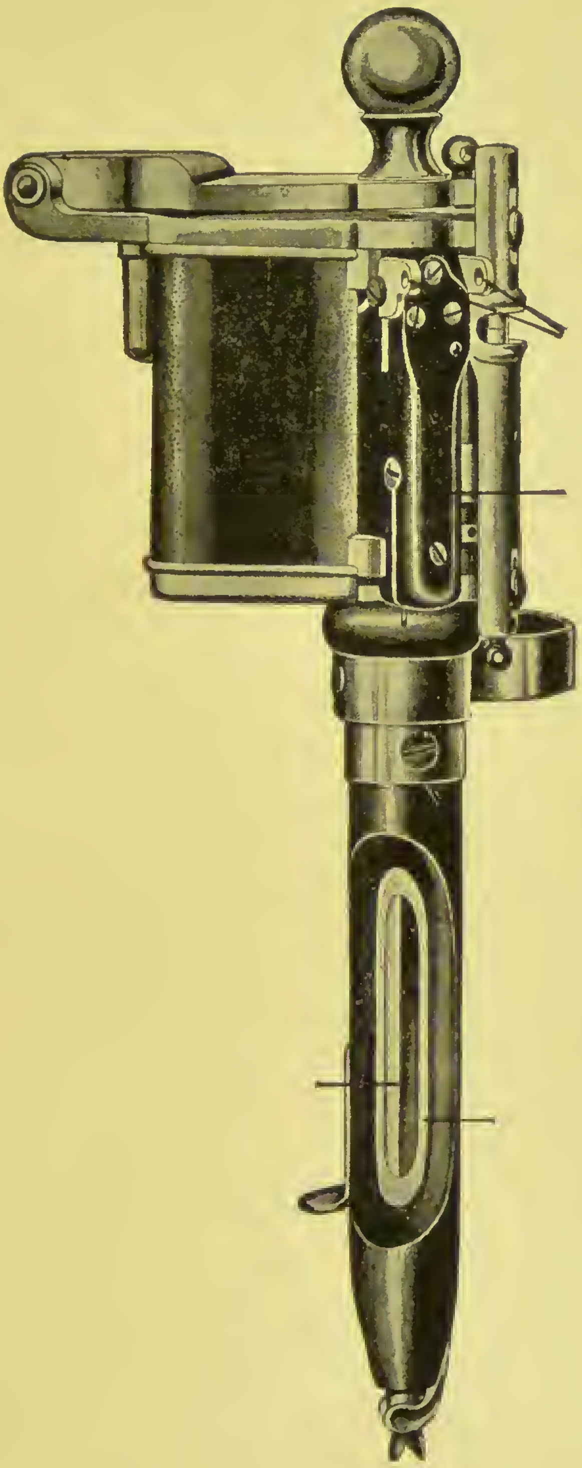

FIG. 121.—BONWILL ELECTRIC MALLET.

operated upon precisely the same principle as an electric bell, except that the current is broken more suddenly. When the armature is at its greatest velocity it strikes the circuit-breaking spring, a point of advantage. Ordinary bell vibrators simply leave a contact point which follows the armature a short distance by the flexibility of the spring which supports the contact.

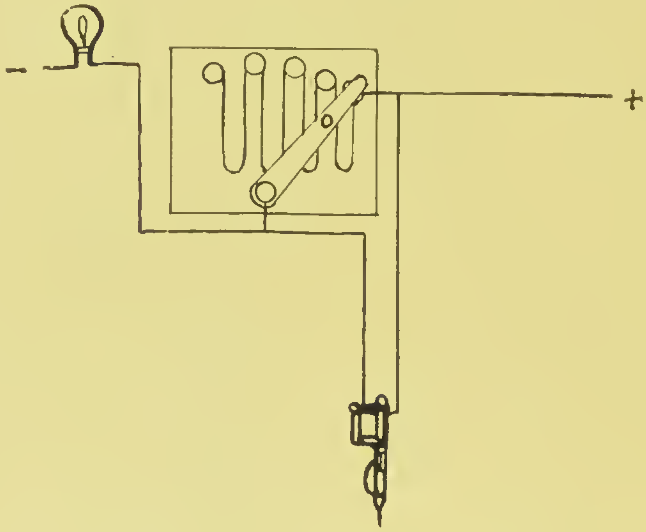

FIG. 122.—ELECTRIC MALLET ON 110-VOLT CURRENT.

The Bonwill mallet while intended originally as a battery instrument, can with proper care be operated by the commercial one hundred and ten volt current. In so doing the greatest care must be exercised in insulating the wires of the plugger from the metal work, and also as a further precaution to insulate the chair from any gas or water pipe.

If it be desired to use a former battery mallet upon the one hundred and ten volt current without rewinding the magnets, the procedure should be as follows: Use

a fifty candle-power lamp as a main resistance, and in series with that insert about thirty feet of twenty-four gauge german-silver wire, wound on slate and placed in a resistance box with about six buttons. Then connect the plugger so as to be in shunt with this resistance as diagrammatically shown in Fig. 122. By so doing there will be no destructive spark as there would be if the mallet were placed in series with the main resistance without a shunt resistance. In the operation of the rheostat as diagrammed in the figure, moving the lever to the left increases the blow of the mallet and to the right decreases it.

If the magnets were to be rewound with No. 34 silk-insulated wire, a thirty-two candle-power lamp on each side of the rheostat and plugger will give the proper resistance, and at the same time protect the patient from a heavy shock in case of accidental grounding.

The S. S. White Company also supplies an electric mallet of the Bonwill pattern, to be operated by an alternating current. This current is derived from a motor generator especially designed for the purpose, and shown in Fig. 93. The motor part is intended for driving a dental engine, and the dynamo end for operating the electric mallet and other small electric appliances.

About the year 1880 an instrument under the name of the Gibbs Electric Mallet appeared upon the market, but for some reason this never came into general use. It was ingenious and simple. The handle was hollow and contained one electromagnet, which was fixed in the lower end. In the upper end was a soft iron plunger which was drawn toward the electromagnet

on closing the circuit. In so doing it strikes the end of a plunger which is movable through the center of the electromagnet.

This plugger is very convenient to handle, inasmuch as it is perfectly round and is not weighted at its upper end as is the Bonwill.

The author, in the following year, constructed an electric mallet, somewhat upon the same lines. The principal point of difference, however, was in the electro-magnetic part. Instead of having a dead weight for the mallet which was unnecessary, two very small electromagnets were used, the first of which was fixed

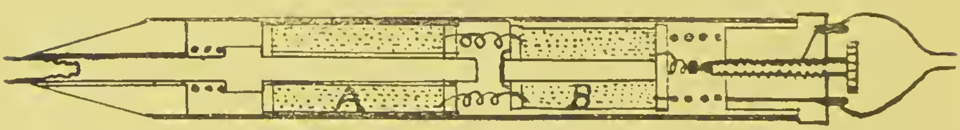

FIG. 123.—THE CUSTER ELECTRIC MALLET.

and the second movable. The arrangement of these is shown in Fig. 123. The magnet A, the fixed magnet is hollow. In this is a soft iron rod which serves both to hold the plugger joint, and as a core for the magnet A. This is free to move in a length-wise direction, and is always kept protruding through the magnet by means of a spiral spring. Magnet B is solid throughout, but is free to move in the shell of the plugger handle. A spring normally keeps this magnet about one-eighth of an inch from the movable core of magnet A, but when the circuit is closed the two magnets attract one another and, A being fixed, B is drawn toward it and striking upon the movable core delivers its blow to the plugger point. The two mag-

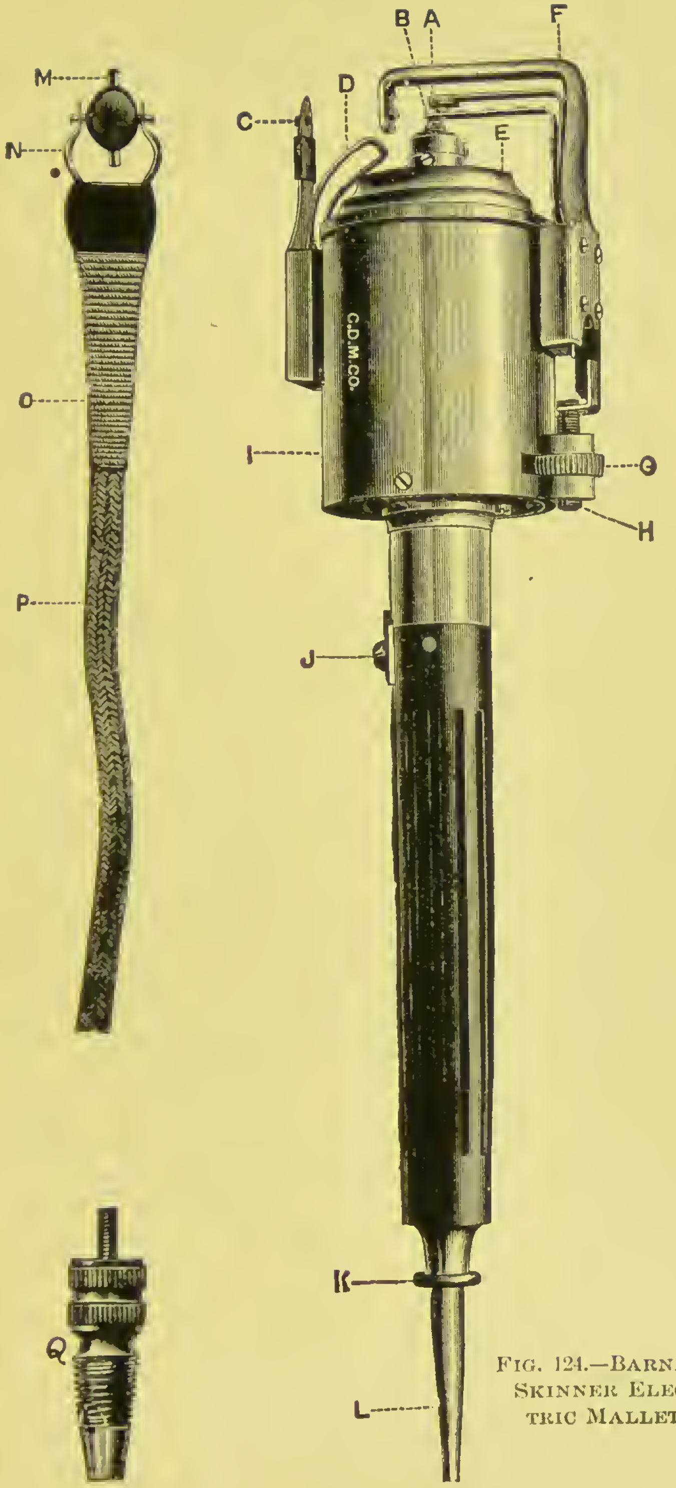

FIG. 124.—BARNES-SKINNER ELECTRIC MALLET.

nets have a continuous circuit in series so that the facing poles attract one another. Just as magnet B is about to deliver its blow, the circuit is broken in the top of the plugger, electric vibrator fashion, when it returns to

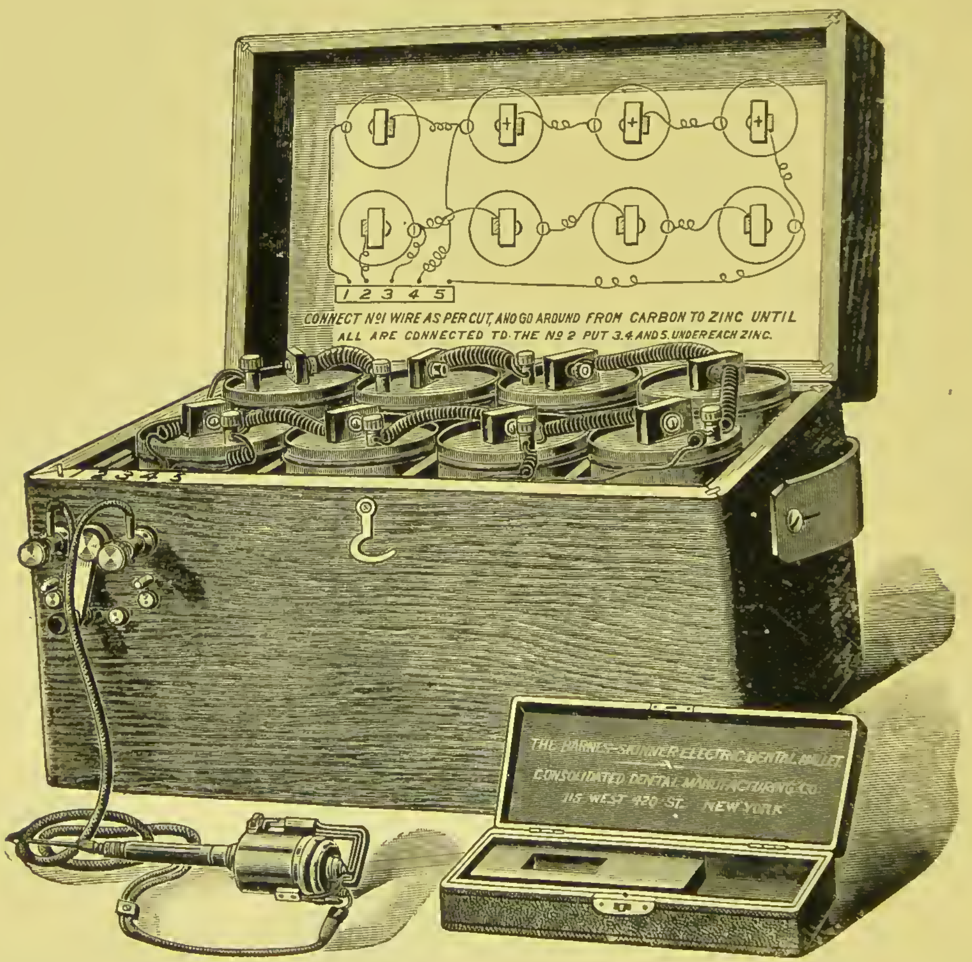

FIG. 125.—BARNES-SKINNER MALLET WITH BATTERY OUTFIT.

again close the circuit. The screw in the end regulates the strength of the blow.

A foot-switch opens and closes the circuit, it being

desirable not to complicate the plugger with this device. Moreover in practice it seems more desirable to do this with the foot than with a button on the plugger.

The Barnes-Skinner Electric Mallet as shown in Fig. 124 is a compromise between the Bonwill and the Gibbs, and also has features not possessed by either. But one electromagnet is used in its construction. This is seen at the top. Still beyond this as a cap to the instrument is a soft iron armature which has the mallet function. In this respect it resembles the Gibbs in principle, but it is an improvement in that the mallet is free to move without any side friction of consequence. In the Gibbs and in the author's, the friction of the movable part upon the sides of the casement would at times affect the blow, unless the operator would humor its peculiarities.

The Barnes-Skinner Mallet is wound for battery use, which we would always recommend for the electric plugger because of its safety from shocks. Such an outfit is shown in Fig. 125.

When the instrument is to be used on the one hundred and ten volt current a main resistance lamp is used, and the mallet is operated in shunt with another resistance which is furnished in the rheostat. This is shown in Fig. 126.

Too much cannot be said as to the importance of insulating the patient and the chair from water and gas pipes when any electrical instruments are to be operated by a commercial current. While there is not much danger of a fatal shock from any commercial current

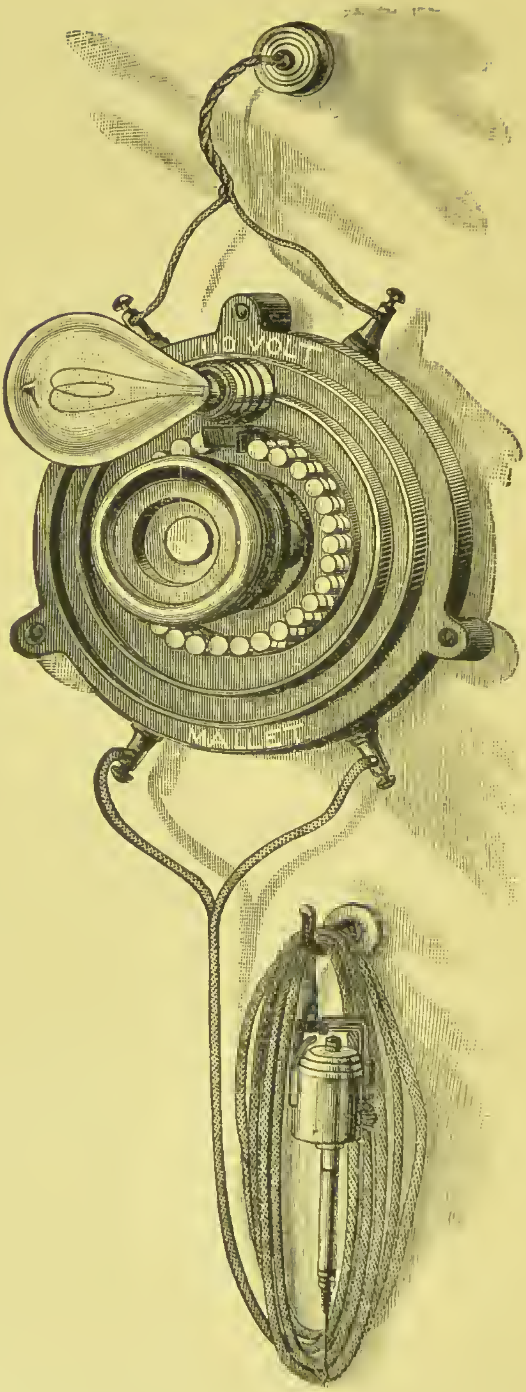

FIG. 126.—BARNES-SKINNER MALLET FOR 110-VOLT CURRENT.

used for incandescent lighting, there is always danger of an unpleasant one. The shock that may be received from the one hundred and ten volt constant current or the one hundred and four volt alternating current is even unpleasant when connection is accidentally made by the hand, but it is much more so if the current is received through other parts of the body. The lips and teeth are nearly always wet and they furnish the best of conditions for making an electrical connection. They are, moreover, especially sensitive to electric currents. While the commercial currents of even the lowest voltage demand careful insulation of the patient from any possible grounding, this precaution is still more important when using the two hundred and twenty or five hundred volt current at the chair. There may be no direct metallic connection between the metal work of the chair and the water pipes, but the column of water in the rubber tube which connects the pipes with the fountain cuspidor has sufficient carrying capacity to supply the conditions for an electrical ground. It is the practice of some operators to burn gas instead of alcohol at the chair, and to conduct the same thereto by means of metal tubing. The possibility of accidental grounding through this source should also be provided against. It is a simple matter to insulate the chair from gas and water pipes, and a set of fiber bushings should be used at the fastening of the fountain cuspidor to the chair.

CHAPTER VII.

HEAT.

IN taking up the subject of electrical heat, we are dealing with one which has a greater variety of applications in dentistry than any other electrical phenomenon. We are also entering a field in which, if we consider the importance of the operations performed, and the value of electricity in the part which it plays in these operations, it is unequaled in any art or science. We are considering an agent which on the one hand will give results so accurate and so delicate as to meet the most exacting of dental requirements, and on the other hand an agent which will give the highest heat that it is possible for man to obtain. It is indeed wonderful when we consider that a wire scarcely larger than a thread can convey to the operating table a current so delicately measured out as to anæsthetize sensitive dentine, or to warm a tube for the dessication of dentine, and it is still more wonderful when we consider that along this same wire may flow enough current to melt platinum, or to fuse a porcelain plate.

In considering the useful applications that can be made of electrical heat in dentistry, we find that at the present time there are no less than a dozen, and two of these applications are of the greatest importance. For years dentists have been using impure and uncertain heat for annealing gold and for fusing porcelain, but

with the advent of commercial electricity an agent is found which it would seem was especially designed for these two processes. While the other dental uses that are made of electrical heat are not of the high importance of the two just mentioned, the matter of cleanliness, of simplicity, and the accuracy of their operations are properties which recommend its adoption in dental practice.

The production of heat by electricity depends upon two factors, the quantity or the ampere strength of the current flowing, and the resistance of the conducting agent. As the quantity is increased the heating power is also increased, but this power is not apparent until the current meets with some resistance. The unobstructed flow of any quantity of the fluid does not produce heat. It is only when a poor conductor of electricity is placed in the circuit that we have this manifestation. All metals are comparatively good conductors of electricity, yet these vary in their conductive property as shown in the table on page 36. Silver stands at one extreme and bismuth at the other. Between these two stand all the common metals. Copper is next to silver in conductive property, and by reason of its comparative cheapness is used in the commercial wiring for electricity. It carries the current with but little loss in wasteful resistance. For other purposes, as for instance the cautery, electric gold annealer, and oven, the wire must possess both resistance and a high melting point, and platinum meets these requirements best.

The second factor which enters into electrical resistance is the cross-section of the conductor. With a

given length of wire the resistance increases as the diameter of the wire decreases. That is, a small wire has less carrying capacity than a large one, so that when the same amount of current that can be easily conducted by a large wire is forced through a small one, the condensation, we will term it, produces heat. We therefore see that with the same quantity of electricity at a given pressure, heat is produced according to the resistance of the conducting agent.

THE ELECTRIC GOLD ANNEALER.

In annealing gold as this daily performance is erroneously called, it is customary to pass the gold through an alcohol or gas flame till it assumes more or less of a red heat. The object of this procedure is not to anneal the gold, for that was done by the manufacturer, but to drive off the gases that are condensed upon the surface, or perhaps are occluded within it, principal of which is ammonia. This operation is usually performed by the dentist's picking up a piece of gold with a pair of tweezers and passing it through the flame of a lamp. And it is a common practice even in dental clinics by dentists of high reputation to use a pair of foil tweezers whose points are as large as the pellet itself. They grasp the gold with these points, covering at least one-third of the pellet, then pass it back and forth through the flame till the edges begin to melt and fuse together. It is necessary to do this in order that the part between the tweezer points be brought to the proper heat. Or, if the free edges of the pellet are properly annealed, that part between the tweezers cannot possibly be. Yet, such a piece of gold, even in a half-annealed condition, or

with its edges a fused mass, will be cohesive enough to adhere for the time being. Later on, however, such a filling will flake off, and especially if any strain is brought to bear upon it. The strongest fillings are those in which each layer of gold is fully annealed without at the same time fusing the edges into a thick rim. It might be stated without error that while it is possible to perfectly anneal a pellet over a flame, by taking it up twice in the pliers, having turned it end for end, that is not the practice. The nearest approach of the best operators to this is by using the most delicate tweezers obtainable, and holding the pellet of gold above the flame at such a height that the heat is broadly and evenly distributed and until it is brought to a dull red throughout. This requires time and the utmost care. It is said that a chain is no stronger than its weakest link, and so it is with a gold filling; it is no stronger than the most defective piece of annealed gold in the contour. A single piece of carelessly annealed gold will be fatal to a contour even if every other piece has been ideally annealed.

The second objection to the flame for annealing is the small area of the heat and the inequality of the same. If each piece is to be properly annealed, the greatest care must be given to each annealing. This requires an amount of time that is no small factor in the operation.

The third objection to the flame is the liability to contaminate the gold with the unconsumed gases or the by-products of combustion. If the gold were to be carelessly introduced in the lower part of the flame, it would

be subjected to the influence of the vaporized alcohol; or if it were to be placed in the upper part it would become coated to a certain extent with the products of combustion. In spite of these two faults of flame annealing, the gold will, however, be made sufficiently cohesive to answer all purposes so far as the building up of the filling is concerned. It will not be, however, till strain is brought upon the gold that the defects produced by the impurities of the flame show themselves. Fillings which are built up of gas-contaminated gold show a tendency toward disintegration throughout, while a filling made up of cleanly annealed gold, but with an occasional piece over or under annealed, will flake off in large pieces, or perhaps a whole contour will come off in one piece.

It is true that perfect fillings have been made ever since the discovery of the cohesive property of gold, but these have been made only by the most careful and accurate methods of annealing, methods which have become a habit of the operator. On the other hand the failure of nearly every filling by the loss of the contour, or by the flaking from a plain surface is due to bad annealing. Many an operator lays the blame for these things, and the harshness as it is sometimes called, upon the gold, and its manufacturer, when as a matter of fact the fault was all his own. He failed to perceive that he was melting the gold upon one edge, and not annealing it at the other, so that any kind of malleting, however perfect, could never bring these pieces into a thoroughly cohesive contact of sufficient strength for ordinary service.

The amount of time consumed in annealing gold by the old process, is a considerable part of the operation, especially if the amount of care is observed that the importance of this step calls for. If this work is not done by an assistant, it necessitates changing the plugger for pliers and back again for each piece of gold, as well as the time consumed in the annealing proper.

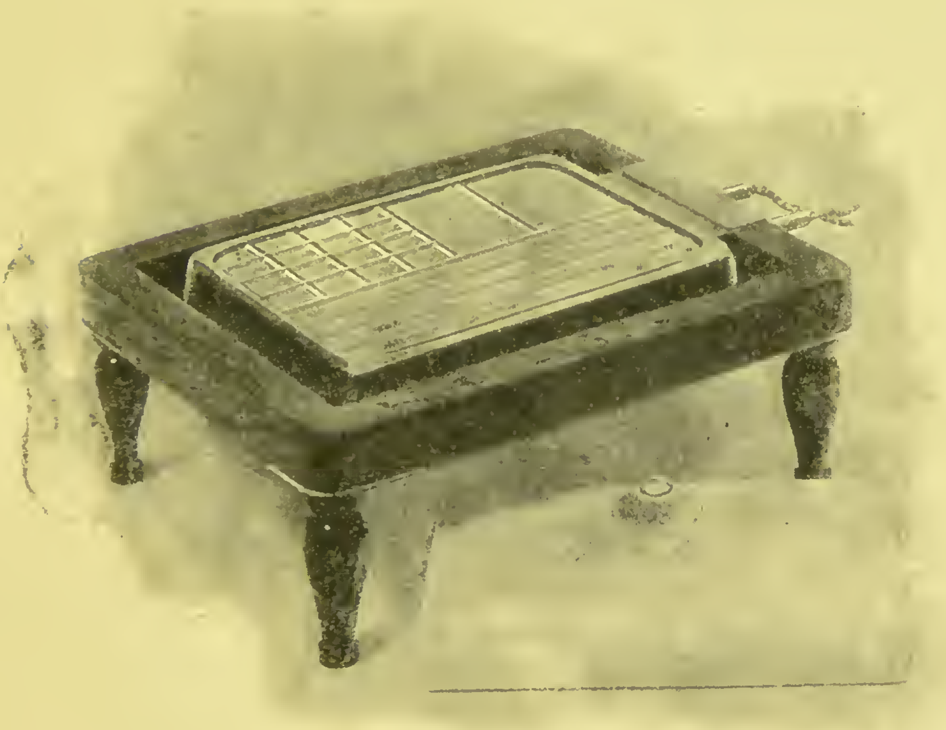

Fig. 127. Custer Electric Gold Annealer.

In order to overcome these common faults of the flame annealing of gold, the author in 1890 invented an electric appliance for this purpose. This in the course of time appeared upon the market in the form illustrated in Fig. 127. It consists of a tray of vitrified fire-

clay through which are distributed fine wires of platinum by which the tray is heated. The tray is mounted in a mahogany frame, the purpose of which is to act as a rest upon which to steady the hand while taking up the gold. The wiring is so proportioned as to take up the full pressure of the current and to produce heat enough to develop the highest cohesiveness of the heaviest foils.

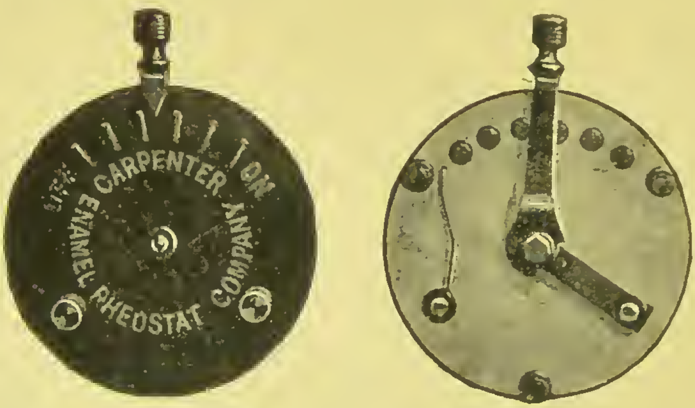

FIG. 128.—WARD LEONARD RHEOSTAT.

If, however, less heat is desired for annealing the de Trey gold, or to develop only semi-cohesiveness for cervical portions of the cavity; or if a very little heat is desired for softening gutta percha upon the cover which accompanies the annealer, an enamel rheostat such as is used for regulating the dental engine, or which can be had of the Ward Leonard Company, of New York, will reduce the heat to any desired degree.

The rheostat is usually of one-sixth horse-power capacity and it will be found to be of service for regulating other dental instruments as well.

The annealer is wound for all voltages up to two hundred and twenty, and can be used on either the direct

or alternating current. In a general way it may be stated that the instrument will operate satisfactorily on any current used for incandescent lighting.

The advantages of the electric gold annealer are many and of considerable value. Probably the most important feature is the purity of the heat. This is derived from a platinum wire which is electrically heated. Platinum itself is a noble metal, it is not oxidized by the heat, and it emits neither vapor nor odor. Platinum is the chemist's *material indestructible.* The wire being electrically heated there is a complete absence of any gases either consumed or unconsumed. The heat of the electric gold annealer is absolutely free from the products of combustion. It is a radiated heat and being radiated from a noble metal, is absolutely pure. When gold is annealed on an electric annealer it is put into a condition of absolute purity. It is customary in the practical use of the annealer to allow the gold to remain on the tray for some time, which insures complete driving off of the contaminating gases.

The second feature of importance is the even annealing of the gold. The tray is so wired that a perfectly even heat is maintained all over the surface. It is not generally known that an equal distribution of wire in electrical heating, even in an enclosed cavity, will not produce an even heat in the oven cavity. There is a tendency of the heat to accumulate in the center, and to overcome this defect the author devised and patented a system of wiring whereby a perfectly even heat can be obtained in electrical heating surfaces which are not true spheres in shape. This system is employed in

both the annealer and electrical oven. The annealer is so constructed as to present a system in which the wires are arranged in a geometrically decreasing distance apart as they are distant from the center of the tray. In this manner the wires in the outer edges of the tray liberate much more heat than in the center, but the circulation of the heat from without inwards, compensates for the lesser radiation of heat in the middle of the tray. This method of wiring produces a perfectly even heat on all parts of the tray so that no matter where the gold is placed thereon, it will receive the same degree of heat.

The third feature is the thorough annealing throughout the pellet. It is customary in using the electric annealer to prepare the gold upon the tray before adjusting the rubber, and about two minutes before the gold will be required the current is turned on. The heat quickly rises and the pellet is at the same time being heated, so that when it is to be used it has the same temperature throughout, and the gases have had time to escape. After this the gold remains the same for hours, in fact as long as the current is flowing in the annealer.

The annealer is so carefully wired for the respective current for which it is intended that the heat rises only a little beyond the limit at which the highest cohesiveness is developed, or about four hundred degrees Fahr. When gold is annealed over a flame it is frequently customary to bring it to a cherry red. This is not necessary for the part of the gold which assumes that color, but for the part between the tweezer points. The cohe-

sive property of ordinary gold foil shows itself at about two hundred and fifty degrees Fahr., and this cohesiveness is increased from that point up to about three hundred and seventy-five degrees Fahr., after which nothing is gained. This heat is not high enough to become visible, and many dentists upon observing the gold would be of the impression that it could not be thoroughly annealed, but clinical use of it shows it to be most highly cohesive. Moreover the heat not being excessive, the gold may be subjected to it for hours at a time, and not be injured in the least thereby. For this reason no special care need be exercised in the preparation of just enough gold for a particular cavity, as any remaining gold can be covered up and used equally well for the next filling.

The electrical annealer has not yet reached a universal application and like many electrical instruments never will, but nearly all those who have used it, speak of electrically annealed gold as possessing almost a new property. Prof. C. N. Johnson in his article upon annealing gold, says of this as follows:

"But the most perfect method yet suggested is through the medium of the electric gold annealer devised by Dr. L. E. Custer, of Dayton, Ohio. With this appliance complete uniformity of result is obtained in the most convenient and ready manner, and with no liability of contamination. Even to operators who have been accomplishing apparently satisfactory results by other means, this appliance will soon reveal a working quality to the gold which seems impossible of attainment in any other way, and it is confidently believed

that its general adoption by the profession would disarm much of the criticism which is occasionally waged against the manufacturers of gold on the plea of lack of uniformity in preparation. The only procedure necessary is to place the pellets in a convenient arrangement on the annealer and turn on the current, which may be allowed to run to the end of the operation. No matter how long the current is on, there is no overheating of the gold. It simply anneals perfectly, without ever fusing any of the layers of the pellets together."

The last feature to deserve attention is the economy of time and expense in operating the electric annealer. The surface of the tray is of hard baked fire-clay, which is naturally rough, and as a further aid the surface is ribbed. The object of this is to prevent the pieces of gold from jarring together, and also to aid in picking them up. The operator in a short time acquires the practice of picking the gold from the tray with the same plugger point that he is using. This can be so dexterously done that the temper of even the smallest point will not be injured thereby. For this reason a vast amount of time is saved as compared with the method of picking up the gold with tweezers and exchanging instruments both ways in so doing. Moreover the time consumed in passing through the flame is entirely done away with. The expense of operating the electric annealer is very much less than that of an alcohol lamp, so that in point of economy in operation, the electric annealer also has the advantage.

THE ELECTRIC OVEN.

Perhaps of all the applications of electric energy in dental practice no one is so important as that of fusing porcelain. It solves the difficulties that have attended porcelain work from its very beginning. The invention of the electric oven marks the beginning of modern porcelain work in dentistry, and it was immediately adopted by the profession for reasons that are obvious. There was not, up to that time, an absolutely certain method of fusing porcelain. With the appliances then in use it was a matter of considerable guess work, and even the most skilled always worked with more or less misgivings, which gradually grew into a state of continual anxiety, as the case neared completion.

Gas and oil furnaces were devised for porcelain work, but while they were more easily operated and consumed less space and fuel, they never produced the clearness of results that characterized a piece properly baked in an anthracite coal oven, so that the prosthetic dentist was ready to accept the new invention with some enthusiasm.

The electric oven made the fusing of porcelain such a simple process that there was a revival of interest in this work, and it may be said to be the foundation and beginning of modern porcelain art. Up to the time of the invention of the electric oven, porcelain work, and especially the construction of full cases, was carried on by the few who made dental ceramics a specialty. The many difficulties and uncertainties attending the heat, made porcelain work a formidable method of practice. The first ovens were large and dirty affairs. This was

true to such an extent that the oven was usually placed in the cellar of the house or in an out-building. These ovens were frequently as large as an ordinary bookcase, so that the space occupied was no small consideration.

The principal objection to this style of oven was the time consumed in obtaining a heat into which it was suitable to introduce the porcelain. Since porcelain is easily affected by gases of any kind which would find their way through the walls of the muffle, it was necessary in the use of this kind of an oven to completely burn the gases off before introducing the piece. For this reason the fire must burn some hours before it would be safe to begin the fusing of porcelain. In the meantime the apartment itself was becoming so uncomfortably warm that the dentist found himself in no condition to see patients, nor was it allowable for him to do so at this time. As a matter of fact, he must shut himself up with the oven till his case was finally finished, the inconvenience of which only the older practitioners are familiar with.

In baking a piece of continuous gum in one of these, there were always so many uncertainties that the dentist was uneasy from beginning to end. The muffle in which the cases are baked would sometimes break and ruin the whole piece. The occasional gassing of a piece, the movement of teeth by the jar of introducing or removing a case from the muffle, and the too sudden chill of the case when putting it into the annealing muffle, as must be done when using these ovens, were but minor troubles attending these old forms.

The difficulty of observing the fusing process was

always present, and yet the experienced dentist did this wonderfully well. He was contending with a large volume of heat and his piece being heated to the same degree, made its observation a difficult matter. It was even hard to make out the piece, much more tell the exact state of the fusion. Experience, however, taught him to gauge the general heat with his eye, which was usually well done considering the difficulties. The artful one, however, in some cases would introduce a cold iron rod over the plate, which would cast a shadow thereon and aid in telling the degree of fusion.

A case fused in this form of oven must be slowly introduced. It is in this way that its heat is gradually raised. The dentist here deals with a fixed heat and his only method of increasing or decreasing the heat of his plate is to slowly introduce it into the oven, and when the case is fused he must carefully remove the same to an annealing muffle, where it is allowed to slowly cool. How different is the electric oven where the touch of a button does it all!

Not only is the fusing of a continuous gum case in a coal oven fraught with difficulties and uncertainties, but the whole process is one which keeps the dentist in a state of anxiety from beginning to end.

The gas and oil furnaces which were put upon the market out of the demand for a simpler and cleaner method for fusing porcelain, while they were smaller, cleaner, and perhaps more economical in their operation, did not meet the most exact requirements of the continuous gum worker in that they did not produce a

perfectly clean and pure heat; moreover, by a contrary nature of things, those which did produce a reliably clean heat did not give one high enough for fusing the higher fusing porcelains. The value of the invention of the electric oven is spoken of editorially in the *Ohio Dental Journal* as follows:

"The invention is a surprise to everybody.

"Think of placing a continuous gum case in the furnace, setting your time regulator, pressing a button to turn on the electric current, and then going about your other business; for the furnace will take care of itself. The heat is gradually raised by means of an appliance arranged for the purpose, and when the body fuses the current is automatically cut off. The case is thus properly baked while you are working at the chair.

"Can you imagine anything more perfect?

"If you prefer watching the process you can do so; indeed, the furnace is so small and neatly arranged that it can be placed on the cabinet beside the dental chair, and the fusing watched while operating.

"Aside from the baking of continuous gum it opens a field of usefulness in other ways. The Parmley Brown system of crown and bridge work is simplified; and the making of porcelain crowns made easier. At a glance it is difficult to fully realize the many advantages this furnace offers, or to comprehend its workings without seeing the appliance. Doctor Custer has revolutionized dentistry so far as electrical apparatus are concerned, and we may add that the end is not yet."

The *Dental Register* says: "This is one of the bright stars in the galaxy of 1894, the discovery of a

method of baking porcelain by electricity; it is not inferior in any way to other great discoveries in electricity by men who are known the world over."

The electric oven was invented by the author in 1894. While the electric annealer was the forerunner of this, it was not until that date that the oven appeared in practical form. The principle is the same in both. If an electric annealer were to be bent in the form of a muffle, it would become an electric oven. The author may be pardoned for going somewhat into the detail of the invention of the electric oven, because of the general usurpation of the invention by unscrupulous manufacturers. Every detail of the oven of value was immediately patented, for the purpose of establishing a permanent record, and of protecting the users of the oven against rascally competition, which we knew would soon grow up. And so it did. Even the priority of the invention was first attacked, but this, at the request of the author, was investigated and settled by a committee from the American Dental Association, which rendered the following:

"After a careful and impartial investigation of all the evidence obtainable, we find that the first practical and public demonstration of the electric oven for fusing porcelain crown and continuous gum dentures occurred in the office of Dr. L. P. Haskell in the month of October, 1894. Dr. L. E. Custer using an electric oven of his own invention and construction, did then and there fuse a practical case for Doctor Haskell. Furthermore we find that Doctor Custer did fuse porcelain by electricity early in the year 1889, while conducting some

experiments with an electric gold annealer, thereby antedating any previous record on this subject.

The committee believe that Dr. L. E. Custer was the first one to practically fuse porcelain in an electric oven, and recommend that this Association accord him that honor." *Signed,*

FRANK HOLLAND,
J. BOND LITTIG,
G. MOLYNEAUX.

Others were at work along the same line, but it was clearly shown that it was not until some six months after the author successfully fused the case of continuous gum in Doctor Haskell's laboratory in Chicago, and not until three months after the entire process was described and shown before the Ohio State Dental Society, that another oven appeared.

The methods employed by one of the first infringers, Dr. H. C. McBriar, were so bold and unscrupulous that inasmuch as many dentists, and even one editor, were made to believe that this fellow had actually invented the oven, we therefore expose this scheme for the sake of the truth. The author demonstrated the oven before the New York Odontological Society in January, 1895, and also at the clinic the following month. Doctor McBriar was present at the clinic and an interested spectator. All his questions as to the construction of the oven were freely answered and on his return home he undertook the construction of an oven for his own use, and even wrote the author for additional data, which were cheerfully furnished him, supposing him to be a professional dentist with the usual allowance of honor

and self-respect. He succeeded so well in his undertaking that he apparently became possessed with the idea that he could modify the oven enough to obtain a patent and manufacture the same. To this end he showed a modified form at a dental meeting in Asbury Park the following August, but the same was not practically operated there. He applied for a patent thereon, and in so doing he met with a patent No. 419,282, entitled "electric steam generator" for the electrical heating of houses, which applied to the very part in which he had departed from the author's for the sake of showing a little originality. He bought the conflicting patent and tried to make the oven under it, but this was not found to be a success; the more nearly he conformed to the patent the farther he got from an efficient oven. At about this time Dr. E. Parmley Brown, of New York, secured one of the author's ovens, No. 17, which as a matter of record, was the same one that the author had used in a demonstration before the Tri-State Dental Society, at Detroit, in August, 1895. Through some arrangement, Dr. C. A. Timmie, then of New York secured this oven from Doctor Brown to demonstrate in Germany. Upon his return, in conjunction with Doctor McBriar, they took the oven apart. Doctor McBriar, using his electrical knowledge, supplied Doctor Timmie with the necessary instruction for the latter to manufacture in Germany, and as a reward to McBriar, he was allowed to bring a collusion suit between himself and Timmie for advertising purposes. The records of this suit were investigated and nowhere in them was found any reference to the Custer oven, or

its users, yet it was so advertised in one journal, and for a single issue only, when they found themselves to be liable for damages. It, however, had the advertising effect for which they were aiming. McBriar, by this time, had found that the patent under which he was sailing, if adhered to, would not meet the requirements, but having purchased it, he still used it for advertising purposes, although making an exact duplicate of the Custer oven, No. 17. As a further matter of record the editor of "Richardson's Mechanical Dentistry" describes and gives McBriar credit for the invention of the electric oven, when as an absolute fact the very cut used in illustrating the article was taken from the author's oven, No. 17. When Doctor Warren was called to time for this misrepresentation of facts, he gave as his excuse that the author when demonstrating before the Academy of Stomotology as the editor of the above-mentioned text-book, had not shown him the proper attention, and therefore he chose to give McBriar the credit for the electric oven. The article is principally a reprint from McBriar's printed circulars. At the close of the author's demonstration at the Philadelphia meeting, a great many questions were asked and not all could be answered at once, and yet no discourtesy to Doctor Warren was intended.

The whole question of the value of the patent, which McBriar was using for advertising purposes for dental ovens, hinges on this: If of any value, why had the electric oven been withheld from the dental profession from 1891 till 1894, when the author invented

his? The dental profession should have had the electric oven in 1891, when O'Mera, for he is the inventor of McBriar's patent took out his patent for "electric steam generators." This patent, by way of further explanation relates to the heating of houses and controlling the heat by means of a rheostat in the living room, and has nothing to do with electric ovens. But it answered for advertising purposes.

The foregoing is but one illustration of the unprincipled competition with which all inventors and manufacturers have to deal.

The form of the oven invented by the author was a departure from the usual muffle-shaped ovens. This was for the reason that we were no longer dealing with heat derived from a flame or a bed of coals in the midst of which the baking was always done. In the construction of the electric oven, the heat is generated in the walls of the muffle and the walls are given a shape to conform to the outline of the piece treated, for the important purposes of producing an even heat for the case, and for economy. This was a radical departure from other ovens and it took some time before it was fully comprehended that it was in keeping with the conditions met with in the new methods of heating. In the old method for full cases it was customary to manipulate the case in the presence of the heat, whereas, in the new it is the method to manipulate the heat and it is not necessary to move the case from the beginning to the end. For this reason the oven may be made of a form and just large enough to contain the case. For electrical considerations it is divided into two halves, the wiring

of each of which in the full case size, is an exact duplicate of the other. In the crown and bridge size the line of division for the sake of convenience is placed flush with the bottom so as to present a plain surface and facilitate the placing of the most delicately constructed crown or bridge. In this the wiring of the top of the upper half is a duplicate of the floor, and the wiring of the side walls is perpendicularly arranged.

It was difficult for the older practitioners to fully realize that in the baking of a piece in an electric oven it was so simple a process as placing the piece in the oven, turning on the current till it was fused, and leaving the piece in the oven to cool and temper. They held the belief that it should be placed in a muffle to cool. To meet this idea some of the ovens are cut down in front so as to facilitate the removal of the piece. The author, however, from his experience, is of the opinion that there is no necessity for removing the piece from the oven till it can be done with the bare hand. The heat goes down so quickly after turning the current off that there is no danger of overfusing and no necessity for removing the case. Moreover, the claim is made that the oven itself is the best annealing oven that can be had, and that a piece which is allowed to remain in the oven till cool will be of much finer temper than one which has been removed to an annealing oven. For this reason the oven recommended as giving the most satisfactory results is the form illustrated in Fig. 136. Its wiring is simple and the front and rear openings are in the best possible positions for observing the case.

The outer casing is of iron which has inwardly pro-

jecting lugs for holding the clay lining on the inner surface of which are strung the wires. These are electrically heated and are the esential part of the oven, and it is to this that we shall give more special attention. The wire is of the following dimensions, to consume the current at one hundred and ten volts: For the small oven, sixteen feet of .014 to .015 gauge; for the large oven the same in each section; for the extra large, seventeen feet of .016 to .017 in each section, the large end being for the negative connection when used on the constant current. If the oven is to be used on the alternating current, although it is not recommended, the wire should be of the same size throughout, .015 in the small oven and .017 in the large ovens. When used on the fifty-two volt current connections are also made in the middle of each length.

The first thing to be borne in mind is that the melting point of the heat-giving wire is but little higher than the porcelain which is to be fused, and yet it is within this narrow margin that we are working. It is therefore important to take advantage of all the conditions that will tend to secure the fullest and most rapid effect of the heating agent upon the object treated. In other words, the closer we can bring the porcelain to unobstructed heat-radiating wires, the less heat will be required of the wires, and the margin between that and their fusing point will be greatest, and in proportion as we remove the object from the source of heat, or introduce an obstructing partition must the heat of the wires be raised. It is the taking advantage of all the conditions which favor the effective application and

conservation of the heat, and the carrying out of the wiring in its finest details that makes the electric oven a practical instrument.

In this oven the wires are laid on the surface itself, the aim being to invest them only deep enough to support them while so highly heated. In putting the first ovens upon the market it was necessary to cover the wires with a thin layer of clay for the purpose of protecting them from metals and other substances which the experimenting dentist would introduce. But later on, as the dentists learned the peculiarities of the electric oven they were sent out with the wires fully exposed. In so doing an important point is obtained, for the introduction of anything between the wire and the porcelain, necessitates a higher heat of the wire than would be necessary were nothing intervening. The wire is embedded just deep enough in the clay to be caught. It matters little how much they may become exposed by use, so long as they do not buckle to the extent of touching neighboring wires, no harm will be done. As a matter of fact the more the wires free themselves from the clay the more efficient the oven will become. Practical observation of this fact later on led to stringing the bare wires upon lugs. It will be seen then that the introduction of an intervening wall or the winding of the wire around the outside of a muffle of clay with the intention of fusing a piece within, will require the wire to be heated to a much higher degree, to produce an equal result within.

The second feature is that the heating wires of this oven are the shortest practical distance from the piece

to be fused. The further the wires are placed from the porcelain, the higher must be the heat of the wires to produce the same result. When a wall is introduced between the two, the obstruction not only causes loss of heat by conduction, but it necessitates the removal of the wires from the piece just the thickness of the wall further than they would otherwise be. Hence, an oven with a wall of clay between the wire and the porcelain demands an additional difference of temperature between the two, for the reason that, the fusing point of the porcelain always remaining the same, it is necessary that the heat of the wire should rise still nearer to its melting point to compensate for the non-conduction of the partition, and over and above this, the additional distance occasioned by the partition itself. So it will be seen that a wall does two things: it interposes a non-conductor, and it removes the source of heat from the object treated.

The third, and most important feature of this oven is the complete covering of all the walls with heat radiating wires. Since the heat of the oven comes from the wires it is evident that the more wires there are for radiating the heat, the less will be required of the individual wire. For this reason the wires are not only arranged as closely together as it is possible to arrange them, but all the walls are completely covered and are heat-producing surfaces. If, for instance, a cavity were to be raised to a certain heat, two wires might do this very easily but one wire in doing it must be twice as hot as either of the two. And so it is with the electric oven. If one side of the walls were blank, or if as

in some ovens both ends are not heat-producing surfaces, it is necessary for those walls which do produce heat, to be raised to a much higher degree than would be otherwise required, in order to make up for those walls that do not radiate heat. This means overheating of the wires and early failure of the ovens from crystallization which appears to take place in overheated wires. While the covering of all the walls with wires is a most essential point for the longevity of the wiring, it is also important, in fact necessary, for producing an even fuse in a full set of continuous gum. A muffle-shaped oven, with only the side walls heat-producing surfaces, and the ends blank surfaces, cannot produce an even fuse of a full set of continuous gum unless it is very large. In fact it must be large enough in diameter and long enough to take in at least three sets of teeth, to insure perfectly even fusing of one full set of teeth when placed in the middle. This is not as they are found on the market. There is scarcely more room than is necessary to close the door. A case can be fused in these ovens it is true, but it is usually necessary to bring the case to a very high fuse on the sides to insure sufficient fusing of the ends. This is very clearly seen in a half-fused case, but when the heat is carried higher till all parts are fused, it becomes a difficult matter to detect over-fused from properly fused, by the eye. Only the test of usage tells an unevenly fused plate.

The fourth feature of this oven and which we may also say is important, because it has to do with the wiring, is the arrangement of the wires to produce an even heat. In practice it was soon found that there was a tendency

of the heat to accumulate in the center. It was found that in all cavities not truly spherical in shape, if wound with wires the same distance apart, the long diameters would not become as hot as the short diameters. To meet this law and produce an even heat, beginning at the points most distant from the center, the wires were wound as closely together as they could be arranged without touching laterally, and as the center was approached the distance between them was in-

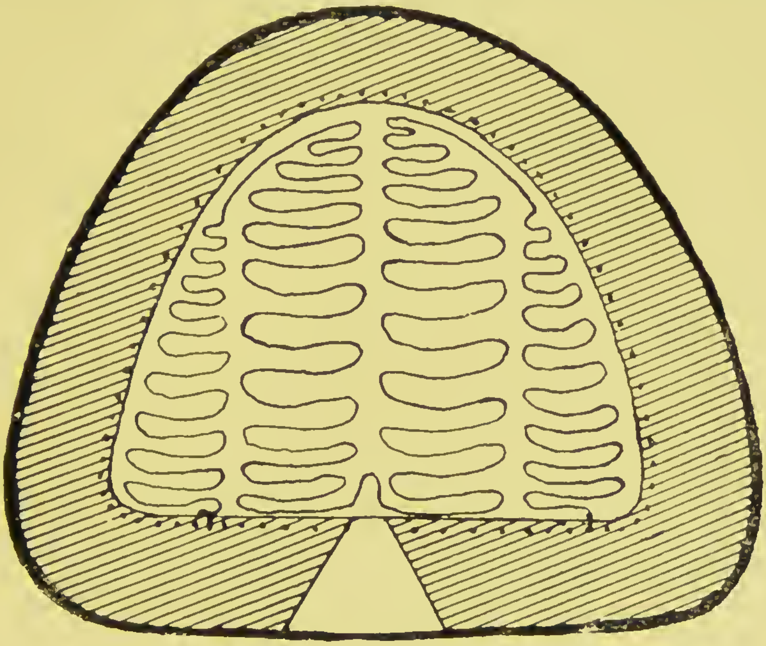

FIG. 129.—DIAGRAMMATIC ILLUSTRATION OF SYSTEM OF WIRING.

creased. The exact distance was only arrived at experimentally, and it was finally found that there would be required about three times the amount of wire in a given area in the most distant point of a Custer oven, that would be necessary in the center. The effect of winding any oven with wires equally distant on all the heat-producing surface is obvious. It means two things, first the

wires in the center become overheated by the accumulation of heat, and second the porcelain is unevenly fused.

The fifth detail was an improvement in the wiring, arrived at only after the study of the working of over a hundred ovens. It was not generally known, if known at all, that the negative end of a wire when heated by a constant current becomes about one-fifth hotter than the positive end, and as yet there has been no satisfactory explanation of the same. The unequal heating does not become apparent in a wire heated in the air, but it is present in the electric oven, and accounts for the trouble that arose at the negative end. It was found that the burn-out always occurred at this end of the wire, because of its overheating. This trouble was quickly overcome by using a wire which was a gradual taper from one end to the other, with the larger end at the negative. In making the negative end one-fifth larger on cross-section than the positive end the wire would be heated the same throughout and such an oven would not burn out when properly used. It is obvious that while this method of wiring is an essential point when the oven is used on a constant current, the conditions would be just the reverse if the current were to be connected in the wrong manner, with the negative to the positive.

The foregoing are the essential points in the electric oven. They are the ones, the observation of which makes it a possible and practical instrument for fusing porcelain. All these features were covered by patents to the author for his and the dentists' protection. In addition to these features there are two others of which

it would be well to speak; one being the detail of the wiring, whereby they are kept in place, and the other to facilitate observing the case while it is fusing. While platinum and the fire-clay expand and contract much alike, there is still a little difference. To meet this the wires are arranged so as to form a continual curve from beginning to end, a section of which is illustrated in Fig. 130. Placed in this manner movement takes place in very small segments of an arc and there is no tendency of the wires to break from their fastenings.

The other feature is the use of two small openings for observing the fusing of the porcelain. The heat of the electric oven is so intense and the light is so bright and even that it is difficult to clearly make out the fusing of the porcelain. To overcome this difficulty two openings are made, a small one in the top for the admission of a ray of different colored light from without, and a larger one in front for observation. The rays of light entering at the upper opening are reflected by the plate through the front opening. This brings out the process so clearly that even the inexperienced can see and understand the fusing as it progresses. While it was originally intended to use sunlight through the small opening, the uncertainty of obtaining a light from this source at all times led to the author's invention of an arc light for this purpose as shown in Fig. 133. When the porcelain has about reached the fusing point and the lever is on the last button of the rheostat, the operator strikes a small electric arc in front of the upper

FIG. 130.—SECTION OF WIRING.

small opening, which shines down into the cavity upon the plate. The observer from in front can now see with as much distinctness as if the oven were open, and can easily tell just how far the fusing has progressed. This feature alone is a most pleasing one, for while the dentist can time his oven much as he would a vulcanizer, he cannot be certain of getting precisely the same fuse every time. The use of the arc light makes him independent of any mechanical appliance and gives him an opportunity for modifying the process to suit his most critical taste.

The advantages of the electric oven are many. It is the ideal method of fusing porcelain. The heat being derived from an electrically heated platinum wire, its purity is insured. The ever-present liability of gassing in the older forms of ovens, is overcome at once by the electric oven, for it does not derive its heat directly from combustion. Its heat is a radiated one and that from a noble metal which does not oxidize. The first and most important requirement is for this reason most perfectly met.

The second requirement is the intensity of heat. Since platinum is the radiating metal its fusing point is also the limit of the heat. This, fortunately, is somewhat higher than any legitimate use in porcelain fusing calls for, and as a matter of fact the electric oven under intelligent management will give a higher heat than any other incandescent oven in use. The tooth carving bodies which have the highest requirements for heat in dentistry, can be fused in the electric oven, the only

requirement being that the piece be watched and the current turned off when it is fused.

The ease with which the electric oven can be controlled by means of the rheostat is a third feature. The rheostat puts this under the absolute control of the operator. Some manufacturers, as a selling dodge, advertise that a rheostat is not needed with their oven. It is not necessary to use a rheostat with any oven for that matter. It is not essential to the oven but is a convenience which the dentist who knows, will not be without, and especially when fusing a full case. The rheostat like a gas valve is the means by which the heat is raised or lowered to suit the operator. When a piece is fused in an oven without a rheostat the heat rises at a rate which he cannot control in any way. The practical method of fusing porcelain pieces as it is generally performed, is to give a length of time somewhat proportionate to the size of the piece. A single crown can be fused in twelve minutes from the cold oven, but a full case should not be fused in less than thirty minutes beginning with a cold oven. This cannot be done except by the use of a rheostat. The fact that most operators who buy a cheap oven because it is advertised as not requiring a rheostat, afterwards buy one, is evidence that the rheostat is a valuable adjunct. When the rheostat is used the dentist has absolute control over his oven, and the amount of time that it saves him will pay for the investment in a short time. Moreover he can do with that something that cannot be accomplished in any other way. He can slowly approach the fusing heat and then throw the full heat on with a suddenness that brings

out the color of the gum in its most brilliant hue. The life of many pieces of porcelain is destroyed by keeping them too long near the fusing point. When the rheostat is not used there is a long drawn out heating below the fusing point during which time the color of the pink gum fades. If this stage can be quickly passed over, as it can be by the use of the rheostat, the life of the gum will be preserved.

The size of the electric oven is smaller than any other. It is scarcely larger than an ordinary dental flask, and for that reason can be used in the operating room as well as in the laboratory. It requires no connection of rubber tubes, bellows, and the like, but in their stead a flexible cord and plug to be screwed in the nearest electrical bracket.

The cleanliness of the oven makes it in keeping with the other appointments of the dental office. More and more the operative dentist finds use for porcelain operations and the cleanliness of the oven permits of its being used in the operating room. It is without gas, noise, odor, or dirt, features which should be preserved in the dental office as far as possible. The electric oven in these respects is a fair illustration of the fitness of electricity in dental practice. It comes in through the conductors quietly and subtly, a horse-power of current may be in operation and we are unaware of its presence except for the exhibition of heat.

Electrical heat, all things considered, costs no more than, if as much as, the other processes of fusing porcelain. The reason for this is found in the economy of heat. In the electric oven there is the most complete

utilization of the heat, but the smallest part being lost by radiation; whereas, in the older forms of ovens only the smallest part is utilized in fusing the porcelain. To fuse a set of teeth takes an amount of fuel in the coke ovens sufficient to heat a house of ordinary size a whole day, whereas the electric oven will not heat in the same way the tenth part of a room for half that time. While electric heat is much more expensive than that derived directly from coal, the comparatively small amount of electricity consumed in the fusing of a set of teeth, makes it very economical.

The electric oven, finally, saves considerable time. In fusing a set of teeth the rheostat is put upon the first button where it is allowed to remain till the case is thoroughly dried out. The dentist may be making a gold filling in the meantime. When he is satisfied that the case is dry, he can throw the lever over two or three buttons at a time according as the interval has been. This is repeated at his convenience till the third from the last button is reached upon which he will allow the lever to stand till he can give the case his undivided attention for three or four minutes. When he is ready he will turn the current on full at once and the oven and case being thoroughly heated, the case quickly drops into a fuse and he is done. Thus the whole operation of fusing a full case occupies but a few minutes of his time and yet he was present at the critical period of the fusing process.

This brings us to the use of mechanical appliances for regulating the oven. While it is possible to use an ordinary alarm clock for timing and shutting off the

oven, still in many offices the voltage varies so much either by the time of day or by the intermittent use of it in large quantities in buildings operating elevators thereby, that this is not a reliable method.

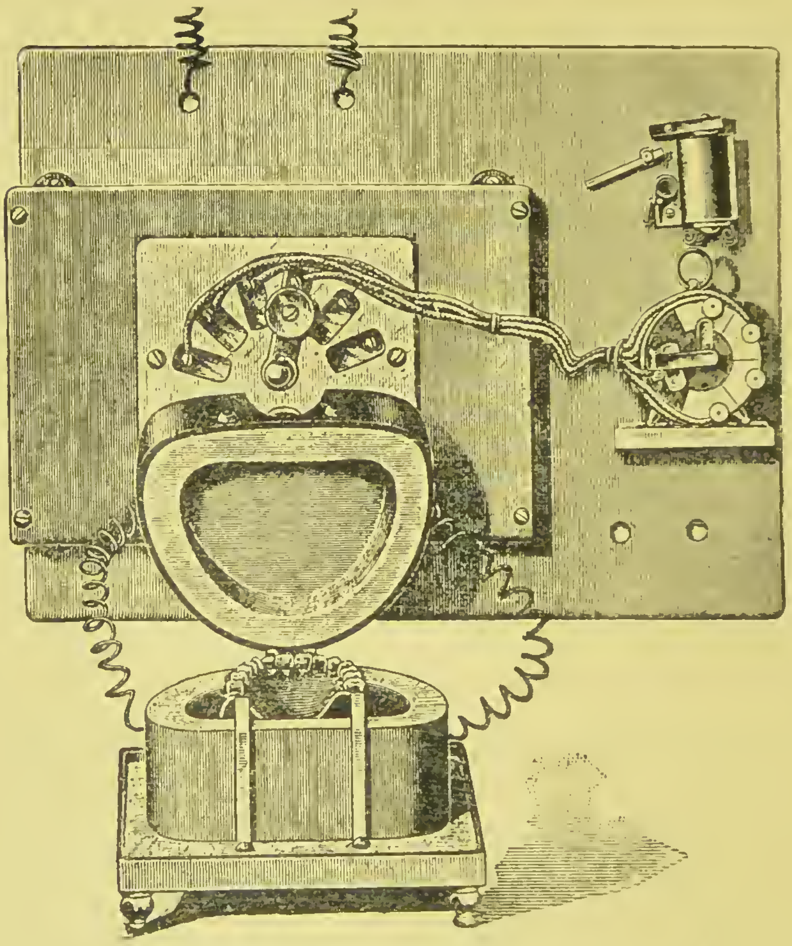

FIG. 131.—AUTOMATIC TIMING APPLIANCE FOR ELECTRIC OVEN.

However, in those offices in which by trial the current has been found to be without much variation, timing the case will be entirely feasible, and reliable results will be had.

An automatic timing appliance was once designed by

the author as shown in Fig. 131. A clock with its minute hand made into a brush which contacted upon four buttons of a rheostat in sweeping an arc, remained for seven minutes on each contact except the last, which was movable. This was set distant from the third according to the material that was to be fused. This appliance worked satisfactorily except for the fact that occasionally the pressure would vary so much as to affect the outcome in the manner previously referred to.

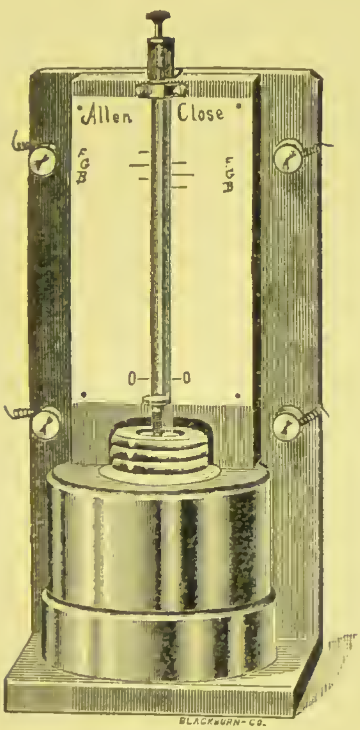

FIG. 132.—AUTHOR'S ELECTRIC THERMOMETER.

The second, and a very accurate method is the use of a watt-meter. This will prove a reliable method and it may be said to be independent of any variation in the pressure. That is, while the pressure may vary the meter records only the amount of current that passes through it, and after all, that is the essential in the fusing process.

If the current on its way to the oven passes through german-silver resistance wire which is embodied in a heavy metal base surrounding a thermometer, the heat of the same will cause the mercury to rise somewhat proportionately to the watts that have passed through the wire. Such a device is shown in Fig. 132.

A method devised by Dr. J. R. Callahan for use with the oven deserves notice. Doctor Callahan uses a high-reading thermometer, placing the bulb of the same in a clay stopper molded to fit the upper opening. This very accurately measures the heat of the oven, especially if the fusing is always started from a cold oven. If, however, the oven is hot at the time of beginning a fuse, the thermometer will read a little higher by reason of the casing being heated at the beginning.

To overcome this one objection to Doctor Callahan's method, the author uses a platinum wire loosely embedded in the clay stopper, one end of which projects into the oven cavity and the other terminates in a cup which receives the bulb of the thermometer. One known as the "pastry" thermometer is used for this purpose. This is about six inches long and reads to six hundred degrees Fahrenheit, the whole appliance being shown in Fig. 133. By using the wire the heat is conducted from the oven cavity more sensitively than by the clay stopper, and the heat of the cup, while not as high as that of the oven, is always exactly proportionate to it, and a scale having once been made can always be depended upon thereafter. If it is desired to be absolutely accurate in the fuse, it can be done by using a pellet of gold which can be seen to melt, as the basis of calculation. It is only necessary to turn off the current when the mercury reaches six points above that at which the gold melts for Close body, or four and one-half points for Close gum.

By the use of the thermometer as above described, it

is possible to fuse porcelain to any predetermined degree with almost perfect accuracy, and it is so easily and certainly done that the operator can relegate the

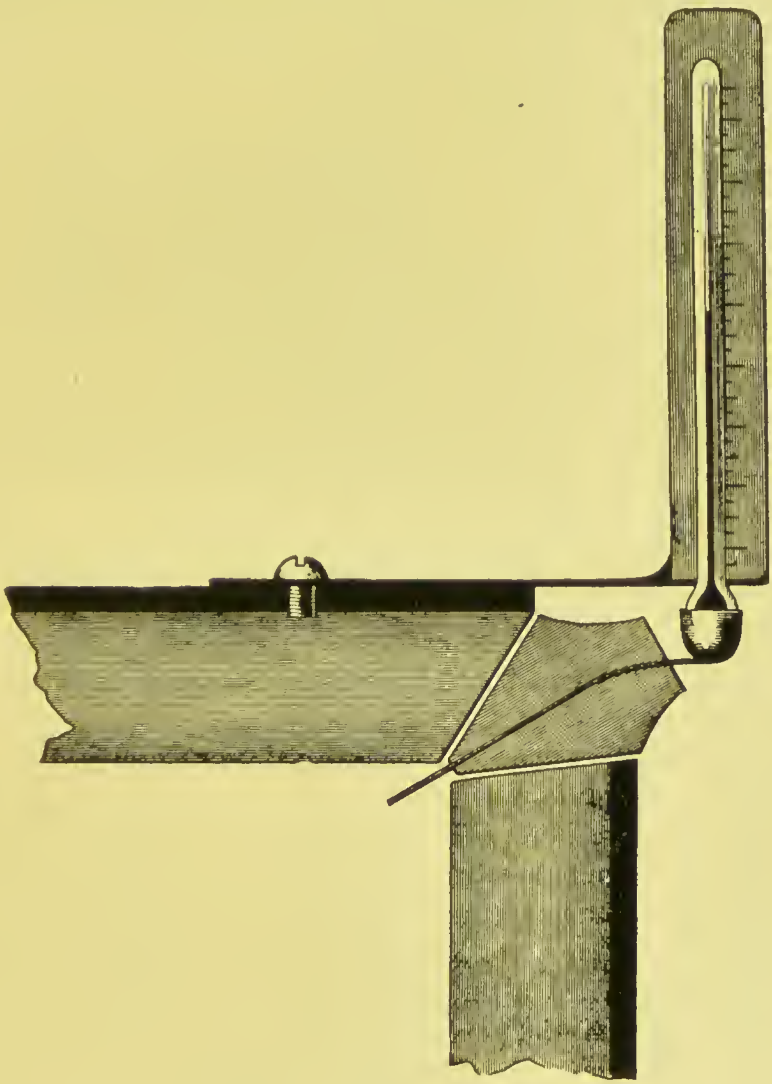

FIG. 133.—AUTHOR'S THERMOMETER.

fusing to his assistant with the assurance that it will be properly done.

The most satisfactory assistant for facilitating the observation of the fusing process is the arc light devised

by the author, in 1897. By means of this adjunct a strong light is thrown in the oven and upon the plate. This light being of a different color from the heat light of the oven and also one of great intensity, will bring out in perfect clearness any part of the plate that it

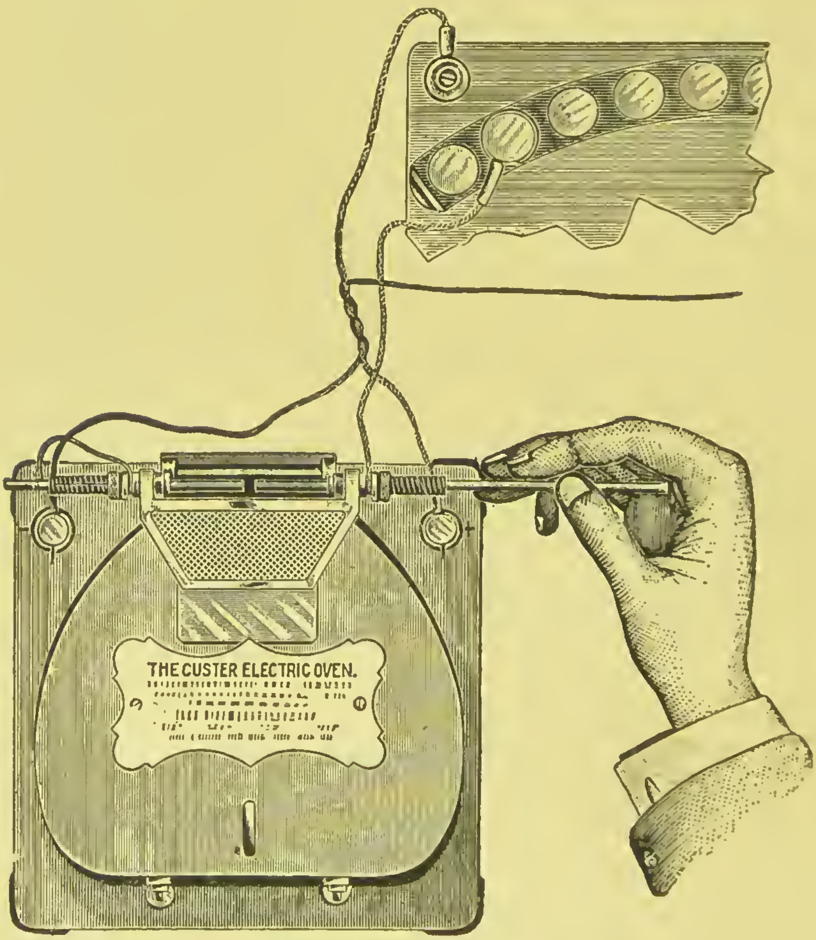

FIG. 134. CUSTER ARC LIGHT.

strikes. Two small carbons are poised on a movable bracket which slips under the name plate of the oven. One of these carbons is fixed in a spring tube and the other is free to move. The operator keeps the fixed car-

bon about the middle of the opening. Then upon touching it with the movable carbon an arc is struck. This light enters the small opening in the top and the operator from in front sees with perfect clearness the part from which the light of the arc is reflected. With this appliance all eye strain is removed, and the operator

FIG. 135.—CUSTER ELECTRIC OVEN FOR CROWNS AND BRIDGES.

can watch the fusing process as clearly as if the oven were open. He can not only see that the case is fusing but he can get a fineness of fuse that cannot be obtained in any other way. While with the electric oven, by ordinary methods the operator has a better view of his case than he ever had in the old-style ovens, the arc light as a finishing touch completes the electric oven for fusing porcelain.

When using the electric oven the dentist should proceed as follows: If the case is a small piece, as a crown or bridge, the lever of the rheostat is put on the first button where it is allowed to stand until the case is thoroughly dried out. When this has been done, the lever can be pushed over to the middle button, and after standing about five minutes at this point, the full current may be put on by pushing the lever to the last button to the right. It might be well to call attention to the position of the rheostat. This should be within easy reach and always placed with the contact buttons at the top. The reason for this is that in case the lever should in time work too freely, it will not accidentally fall over on a live button. While the lever is on the last button the operator should never leave the case. It should be watched till fused. The operator's eye is becoming familiarized with the appearance of the porcelain, and he can be sure of not overfusing the case, as would very often happen if attending to other matters at the same time. The dentist can, when rushed for time, throw the lever full on at once and thus fuse the case in ten or twelve minutes, but this should not become the practice because of the temptation to leave the case before the fusing point is reached. If, however, he acquires the habit of gradually working the lever over to the third or fourth button from the last, and allowing it to remain there until he has the proper amount of time, he will save himself the anxiety, and at the same time be present when the case fuses.

In fusing a full case, at least thirty minutes should be consumed in carrying the case from the cold oven

to a full fuse, and a longer time than this is even better, so long as it is held at a comparatively low heat during the first stages. From personal experience it can be stated that for the purposes of obtaining the strongest plate, and the most life-like appearance of the gum, the heat should be turned on somewhat as a ball rolling down-hill gathers momentum, gradually at first and more rapidly towards the last. It is for this reason that the operator is advised to use a rheostat, gradually bringing the heat up till the third or fourth from the last button is reached where it can be allowed to remain until he can give the fusing his undivided attention. The whole oven has become heated up throughout; the case is at the same temperature and then the lever being thrown on the last button at once, the case quickly fuses. By following this plan the dentist has given the fusing of his case no attention save an occasional pushing forward of the lever and when the third or fourth button from the last is reached, he allows it to stand at that until he has time to complete the operation. The porcelain is just ready to drop into a fuse and turning the lever brings up the heat so quickly that he has had just sufficient time for familiarizing his eye with the heat. The time consumed in the first stages may be even an hour's duration, and no harm will follow. By this method when the case fuses the operator is present at the critical period and yet it has consumed but a few minutes of his time in all, and at no stage of the operation was there any danger of overfusing. Where the method of turning on a button at a time, as followed by some, is used, the time per-

sonal attention is required is so long that the temptation to attend to other things frequently produces an over-fused case.

FIG. 136.—CUSTER ELECTRIC OVEN FOR FULL CASES.

Besides the form shown in Fig. 135 the oven is made in two other patterns and sizes. For ordinary full cases and for all crowns and bridges as well, the oven shown in Fig. 136, known as the No. 2, meets all requirements.

This oven will be found to be the most satisfactory for the general practitioner or one who constructs crowns and bridges and an occasional case of continuous gum. For the specialist in porcelain, however, an oven the

FIG. 137.—HASKELL PATTERN.

same in all respects as Fig. 136 except that it is one half an inch larger in all dimensions would be recommended.

The older practitioners who had acquired the habit of removing the case to an annealing muffle when fused, desired an oven which would permit of this being easily done. The oven shown in Fig. 137, known as the Haskell pattern has the front wall of the lower section removed, thus bringing the front of the casing flush with the bottom. This facilitates the removal of the case.

It is advised, however, that the operator who is beginning in porcelain work use the style shown in Fig. 136, for several reasons: First, the oven itself is the best for annealing that can be had and there is no necessity for removing the case to a special oven for that purpose. If the case is allowed to remain in the oven till all has cooled together, it is most reasonable to suppose that it will be more evenly annealed than when removed to another muffle. In changing the piece from one oven to another, it is subjected to a very sudden change of temperature, which, while it is not sufficient to check the better porcelains, still has no advantage. Moreover, the danger of injury during the removal is avoided. By leaving the case in the oven to cool it is given a better temper and the whole process is simplified. A second advantage in this style of oven is found in the arrangement of the sight openings. These are in the most advantageous position for viewing the case and a much wider range is thereby obtained. A third advantage is found in the system of wiring. In the crown and bridge size and in the Haskell pattern, each half is differently wound, whereas in the No. 2, as shown in Fig. 136, each half is a duplicate of the other. This system of wiring is diagrammatically shown in

Fig. 129. It is very simple and the operator can easily trace it out when making a repair.

When the oven was first put upon the market the wires were covered with a thin layer of clay, as a protection against metals and the like, which the dentist would inadvertently use. After it became generally known that the oven was a delicate instrument in some respects, it was sent out with the wires entirely exposed. The oven is a sensitive instrument and one easily ruined by abuse. The first care that should be exercised is cleanliness. The platinum wires while so highly heated readily take up any foreign substances that may be present. They unite with other metals, thus lowering the melting point of the platinum, causing a burn-out, and many other substances cause a granular effect on the wire. In order to prevent the possible contamination of the wires, a tray should always be used to rest the work upon, and the oven should be kept covered when not in use. As an illustration of what has happened, some dentists use pumice stone in the investment of their cases. This fuses in the oven and if a tray is not used it acts as a flux upon the wires causing a burn-out and an absolutely unreliable condition of all the wires with which the pumice has come in contact. A platinum wire tripod resting upon a tray is preferable to an investment.

Nothing should be fused in the oven but porcelain. It should not be used for the melting of metals for which there is a great temptation. The metals may not touch the wires, but their volatilization, which frequently occurs, is certain to injure the wires by uniting with them.

It should not be overheated; a single overheating will do more damage than many heatings at the proper temperature. A molecular change appears to be produced by overheating. The author accounts for it in this way: The metal of the wires has almost reached its melting point, and under the influence of the current the molecules take on a movement from the relation in which they were placed in the drawing out of the metal in the wire form. This movement of the molecules may be brought about by the high heat long continued, but we are of the opinion that it is also largely influenced by the current itself. This force is probably of an electrolytic nature inasmuch as platinum is not to any extent magnetic. At any rate a crystallization is produced in the wire which is apparent even to the naked eye. It is also proved by the rise in the resistance of the wire. Old ovens consume less current and heat up more slowly than new ones. This is due to the loosening of the molecules and an attempt at polarization, as it were. If in the use of the oven the heat of the wire does not approach so near the melting point that its molecules move from their respective relations, no permanent change of structure will be produced. To be more explicit, it is necessary that these molecules or atoms, during the height of the heat have a wider path of movement, but it is not necessary that this movement should be so much that they do not return to their original relations, when the oven cools. In practice it has been found that if the oven is not overheated a single time, that it will last for hundreds of operations. The author has a record of over eight hundred fusings with-

out a single burn-out. When the oven was first put upon the market it received an immediate backset from this cause. The dentist would invite his neighbors in and put the oven to the highest heat possible to see what would happen, or perhaps, to see if it could withstand all the abuses which he could put upon it. If it stood this test, it was a success and he would keep the instrument, if not, he would return it to the manufacturer. When the oven did not burn out by this trial it would surely do so in a short time because of the crystallization that took place in the wires.

The repair of the oven is a simple process. The clay in time cracks somewhat, but these can all be repaired so as to be as good as new by mixing the repair clay with water, and having first saturated the clay around the break with water, pasting the cracks full of new clay. This bakes hard at the first heating. The wires may sometimes, and especially in large curves, become loosened from their investment. These can be pressed back with a wooden instrument and held with a thin layer of repair clay. It does not matter how much the wires become freed from their investment; so long as they do not buckle to the extent of touching neighboring wires, no harm will follow.

The most troublesome feature to repair is the burn-out which sometimes happens from the causes indicated on previous pages. The first thing to do is to locate it. If the oven is one of large size, the simple opening of the lid while the current is on will tell in which section the burn-out is located. If there is a large spark at the contact springs, then the burn-out is in the lower sec-

tion, and if there is no spark at all the trouble is in the upper section. When both sections are good there will be a faint spark at the springs upon lifting the upper section, and a large spark when turning the current off at the rheostat. Having determined in which section the burn-out is contained, the exact location is the next step. If upon close inspection it is not apparent to the eye, other means will be necessary. The burn-out ordinarily shows itself by a black spot and a fused button of platinum. If it is not apparent, it is then to be tested for in this manner: Use an eight candle-power lamp if obtainable, if not one of sixteen candle-power will answer except that the spark is a little larger. Screw the lamp in a socket with two flexible wires attached, or, solder one wire to the outside of the lamp base and the other wire to the button on the end. Disconnect the oven and fasten one of the wires from the lamp to one of the tips just taken from the oven. This leaves one wire from the lamp and one tip to the oven free. Turn the rheostat to the second button and test the lamp connections by bringing the two free terminals together. If the connections are correct the lamp will light upon touching the points together, and it will go out upon separating them. If the burn-out is in the lower section fasten the free tip to the right hand front spring and beginning down in the same corner with the long flexible wire at A in Fig. 138, pass it along on the bottom of the oven, from wire to wire, first back then forward, back and then forward, which brings us to the left hand front corner. If at any time the light fails to burn when touching an exposed wire, the trouble is near by and can

be quickly located. The wire after covering the base then covers the side walls, going up the side from the left hand corner near B, and passing entirely around in a right hand direction till the left hand front corner is again reached where the wire goes out at B through the body of the clay to the connections.

The upper section having been first taken off, is tested in the same way. The wire for the connections leaves the oven cavity in each of the corners, as with the lower section. In fifty-two volt ovens, in addition

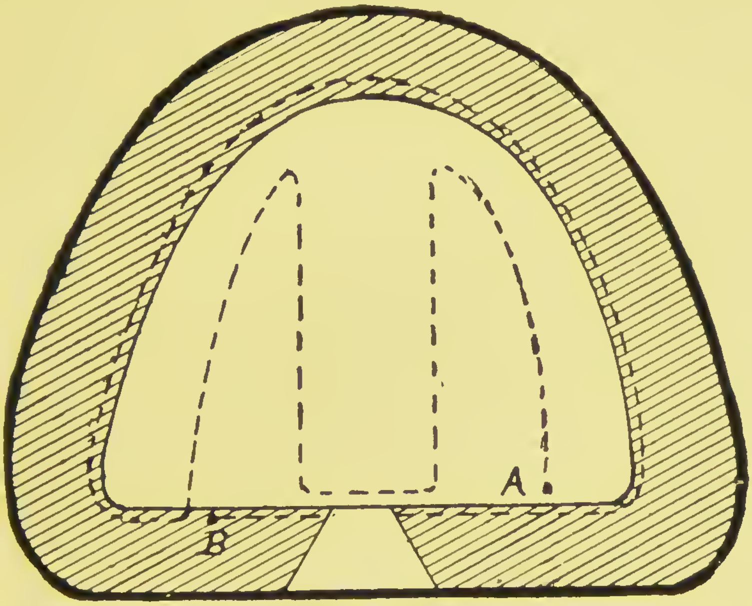

FIG. 138.—PLAN OF WIRING OF THE NO. 2 CUSTER OVEN.

to the two terminals a double connection is also made in the left hand lower corner. The two original terminals are brought out together to the right hand contact in the upper section, or spring in the lower section, and the new connection that is made at the left hand corner is brought out to the left hand button or spring, as the case may be.

When the break has been located its repair is a simple matter. Expose enough of the wires to get a clear idea as to the plan of wiring. The plan of the wiring of the full case ovens is diagrammatically shown in Fig. 129. If it is a burn-out it usually appears at the end of a loop, and perhaps the arc formed was large enough to have burned out two or three neighboring loops. All that is necessary in repairing this form of burn-out is to grasp the two free ends of wire with a small pair of flat-nosed pliers, and having put a single thickness of No. 4 gold between the two wires, twist tightly together, cover with a little clay and heat up. If three or four loops in a row are burned out, it might be well to strip these loops out entirely and bend in a new piece of the wire furnished for the purpose, to take their place, first preparing a bed for them by scraping the clay flush with the bottom of the old print of the wire.

The other form of break in the circuit is that caused in some inexplainable way by the breaking of the wire while cooling. This does not usually occur except when some foreign substance has affected the wire during the heating. This is repaired in the same manner as that just indicated.

In making these repairs the greatest care should be exercised that neighboring wires are not injured thereby. The least scratch is sufficient to cause a new burn-out. A dull chisel will remove the clay and the final ends can be stripped up by gently pulling on them. A wooden instrument should always be used for adjusting the wires.

THE ELECTRIC CAUTERY AND ROOT-DRIER.

While the electric cautery has a somewhat limited use in dentistry, it is of sufficient value, however, to receive attention. This instrument as illustrated in Fig. 139, consists of a vulcanite handle through which pass two heavy copper wires. These wires extend about two and one-half inches beyond the handle. The purpose in having the wires of thick copper, is that they may carry the heavy current that is necessary, without heating, and also to give the proper stiffness at the point. One of these wires is broken at a convenient point in the handle and a small switch inserted so as to bring the current conveniently under control. The two projecting wires are fastened securely together and yet are insulated from one another. At their extreme ends a loop of about twenty-six gauge platinum wire connects the two. This loop varies in shape according to the uses for which it is intended.

FIG. 139.—ELECTRIC CAUTERY.

The cautery requires a volume of current according to the size of the platinum wire. The length of this wire makes but little difference; it is the cross-section that is the troublesome feature because of the large volume of current in amperes required to heat it. A twenty-eight gauge requires about five amperes and a twenty-four

gauge about ten amperes to produce the proper heat. There is required, however, about four volts to force this strength of current through the cautery loop and the conducting wire leading to and from it. It is an easy matter to get a current of this amperage from a battery, but when taking it from the one hundred and ten volt current, it not only necessitates special wiring, but is a very wasteful method. The dental uses, however, do not require a very large cautery and the dentist can usually get enough current without special wiring. If this is to be taken from battery power, two storage cells of about thirty ampere hours' capacity can be used for the purpose. These can be charged either by a gravity battery or by the constant current by using a fifty candle-power lamp in series. The battery can also be put in series with the dental engine and charged when the engine is in operation. As a rule there is enough margin in the power of the dental engine to charge a battery of this kind and still have a surplus of energy. The resistance of a storage battery of that size and capacity is so little as to be practically negligible.

If, however, the dentist chooses to operate his cautery from the one hundred and ten volt current, he can do so by introducing about ten ohms' resistance and taking off enough current for this cautery by a shunt rheostat as described on page 209. By so doing he can open and close the switch in the handle without having a destructive spark. The breaking of six or eight amperes in a series switch that is not in shunt with another circuit, would produce such a large spark as to ruin the

handle of the cautery. By using the cautery on a circuit that is in shunt with another the entire current is not broken when the button is raised. It has still another path through which the current can flow, and the spark at the cautery switch is for that reason very slight.

The cautery can be much more economically operated on the alternating current by the use of a small transformer as shown in Fig. 140. This operates on precisely the same principle as the large transformer. The

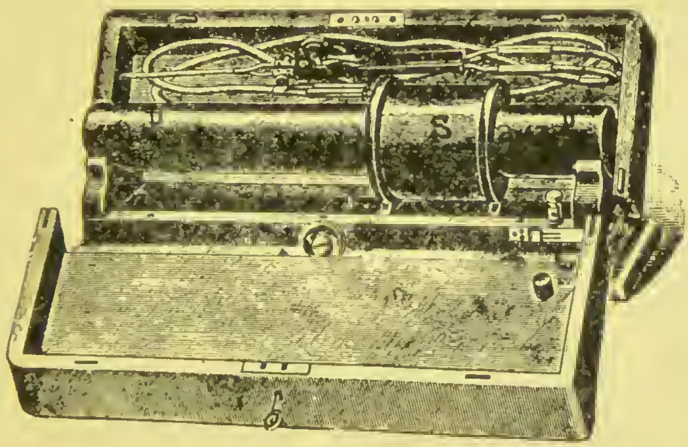

FIG. 140.—ALTERNATING CURRENT TRANSFORMER FOR CAUTERY.

current is received at fifty-two or one hundred and four volts as the case may be and a secondary current of low voltage but high amperage is produced.

One form of an electric root-drier can be made by doubling a twenty-eight gauge platinum wire upon itself and soldering the very tip with pure gold, then dressing this down to a broach-like point. The two free ends are to be fastened to the copper points of the cautery appliance just described. If the two wires do not touch one another from the solder to the copper wires the heat will be carried to a greater distance into the root. In

using the root-drier just described, the heat is obtained by conduction from the platinum point.

The Garhart Dental Manufacturing Company has a very complete root-drier upon the market. The novel feature of this appliance is the method of combining the resistance which is necessary when used on a commercial current, in the flexible cord which conducts the current to the root-drier. In this manner the whole appliance is self contained, it being only necessary to screw the plug in a near-by socket, when it is ready for use.

The root-drier itself is interchangeable with a small lamp shown in Fig. 158.

WARM AIR SYRINGE.

Another form of root-drier and warm air syringe is one in which the heat is obtained by forcing a jet of air over a heated platinum wire and the drying is done by the heated air. The S. S. White Company has a splendid instrument for this purpose which is shown in Fig. 142. This instrument consists of a rubber bulb for producing the air pressure. The point in which the heat is produced is a glass tube containing a platinum coil. This is further protected by means of a perforated metal shield which allows the operator to see the heating of the wire and also prevents to a considerable degree the overheating of the nozzle. The metal point is about the size of a hypodermic needle and can be forced to a considerable distance into the pulp canal.

A small thumb-switch is placed at a convenient position upon the handle for closing the circuit. This is a great convenience, for, the heat of the wire being fixed

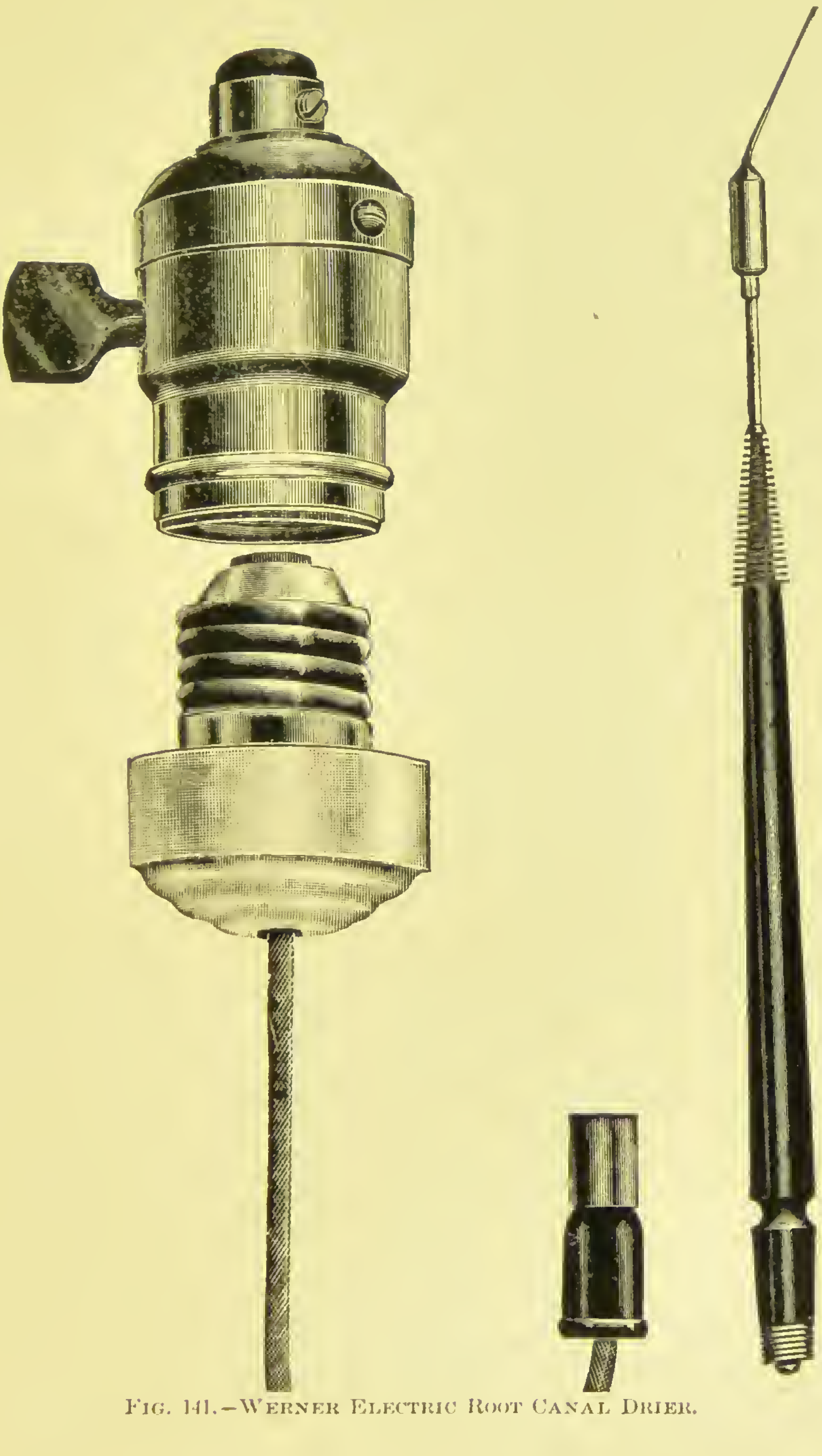

FIG. 141.—WERNER ELECTRIC ROOT CANAL DRIER.

by the current which operates it, the dentist by momentary touches upon the button can obtain a warm blast for sensitive dentine, or by holding the button down for a little time he can obtain a hot blast for pulpless teeth. In this manner this instrument forms a very simple and effective device for either warm or hot air. The temperature of the air can also be varied by modifying the air pressure from the syringe. A light pressure will cause a hot blast, whereas a hard pressure will produce a jet of warm air. The heat of the wire always remaining the same, any degree of heat can be obtained by the simple manipulation of the pressure upon the bulb.

The heat for the platinum wire can be obtained from the S. S. White Company's motor generator outfit as shown in Fig. 93, the Partz Motor Battery, No. 6, or it can be obtained from an Edison-Lelande battery.

In the construction of a warm-air syringe the nearer the heat-producing wires are brought to the tip the better. Dr. J. W. Wassall devised a hot-air appliance in which the wires were contained in the tip itself. The wires were wound on a form, and porcelain baked around them so as to insulate them, hold them in position, and also afford a passage way for the air. In fact the walls of the tip were the heating surface and the air became heated as it escaped from the point. Those who have attempted carrying heated air through a rubber tube of any kind will see the wisdom of this device; for it is impossible to carry a jet of warm air any distance through a rubber tube. Unfortunately this appliance is not upon the market. The Electro

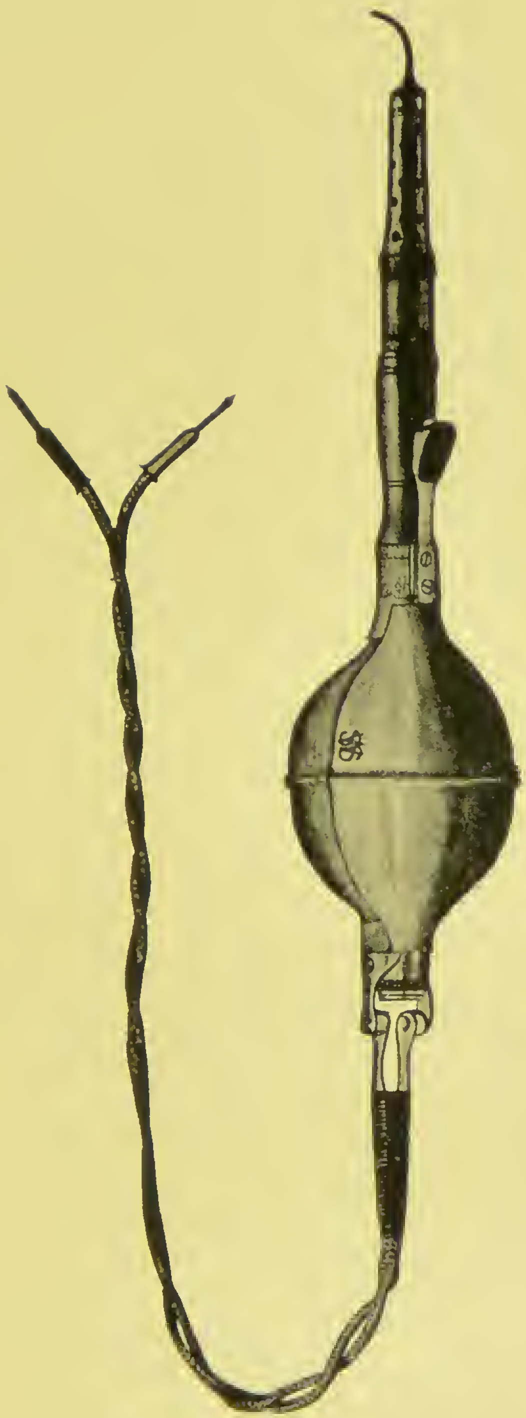

FIG. 142.—S. S. WHITE ELECTRIC WARM AIR SYRINGE.

Dental Company, of Philadelphia, however, has one which embodies nearly all the details of Doctor Wassall's warm-air tip. This is shown in Fig. 143.

In order to produce a jet of warm air at an absolutely even heat, three things are necessary. The air pressure must be uniform, the heat of the syringe must be uniform, and the tip must be held the same distance from the tooth. To have a steady air pressure, one must be equipped with compressed air. This may be anywhere from five to fifteen pounds, but whatever its pressure it must be always the same when using the warm air for sensitive dentine. The best method of obtaining this is to use a sixty-gallon kitchen tank as a reservoir, and keep this supplied by an automatic appliance, such as the electric air compressor described on previous pages, or by means of a water-operated beer pump. All of these appliances can be set to operate at a given pressure.

The heat of the tip must be uniform. Herein lies the value of electrical heat for this purpose. Having once arrived at the proper heat for sensitive dentine and for a pulpless tooth, the rheostat lever can be placed upon the proper button with the assurance that, so far as the electrical part is concerned, the heat will be of the proper temperature. No agent can take the place of an electrically heated wire for this purpose. The absolute reliability of electricity, the purity of the heat, the perfection of control, and ease of manipulation are properties not to be had in any other agent or method.

The distance from the tooth must also be approximately the same. Nearly every dentist by habit places

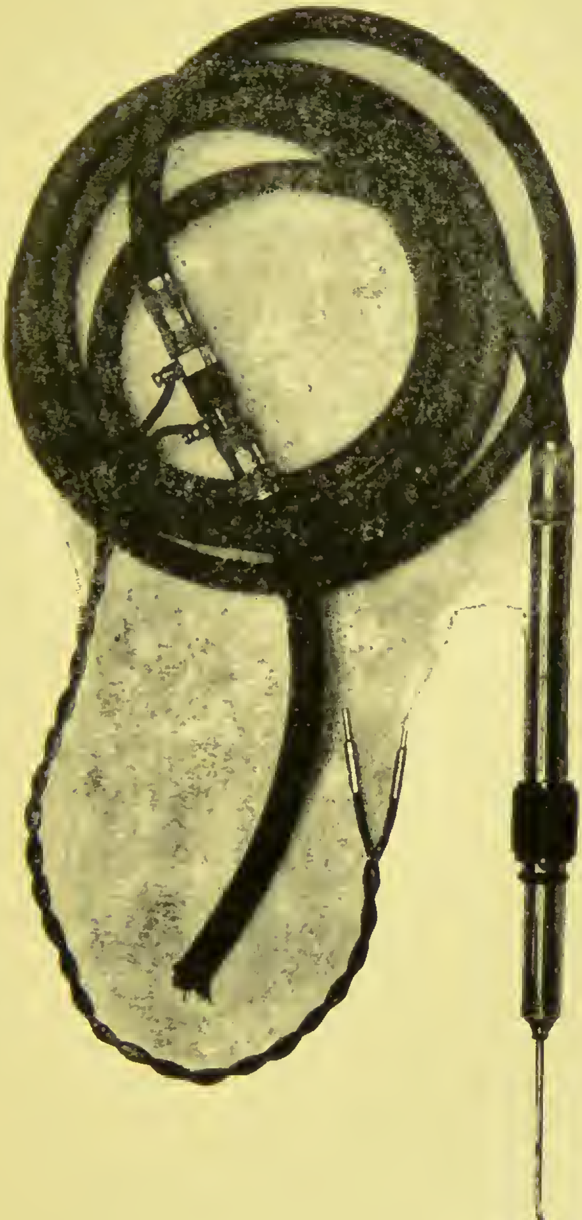

FIG. 143.—ELECTRO DENTAL WARM AIR APPLIANCE.

the syringe point about the same distance from the cavity each time and he can acquire the same habit with the electrically heated tip.

The author exhibited in his dental cabinet at Chicago in 1893 a warm-air appliance which was entirely automatic in its operation. The simple act of taking the warm- air instrument from its place in the cabinet closed the circuit to a small motor in the base of the cabinet and also the circuit of the warm-air appliance in the tip. Both the air pressure of six pounds and the heat of the tip were attained before the mouth of the patient was reached. It also has a valve by which the air is passed through a wash bottle of alcohol or the essential oils on the way to the nozzle, so that if desired, the air is laden with either the vapor of alcohol or the essential oils, and these, too, at blood temperature for sensitive dentine, or as a hot blast for pulpless teeth. This instrument with but slight modification and renewed rubber tube is a most satisfactory one to this day. No instrument is appreciated so highly by the patient as this appliance, and especially those patients who have once had a cavity wiped out with a pellet of cotton saturated with alcohol, itself cold, then followed by a hot blast from an ordinary hot-air syringe.

ELECTRIC GUTTA-PERCHA PLUGGER.

Electric heat has been utilized by Dr. L. A. Faught in the packing of gutta-percha. He has designed an instrument shown in Fig. 144 in which the plugger point is kept at a constant heat by an electric current. The current is conveyed to the instrument in the usual

manner and the heat may be regulated to any desired degree by means of a rheostat.

The advantages of this instrument over one heated over a flame are three: The heat can be perfectly controlled by means of the rheostat, there is no danger of overheating the gutta-percha, and the instrument maintains a constant heat throughout the operation.

FIG. 144.—DR. FAUGHT'S ELECTRIC GUTTA-PERCHA PLUGGER.

ELECTRIC STERILIZER.

We now come to three simple devices operated electrically, which although not essential are great conveniences, and where the dental office is equipped with a current for other appliances, they can be added with very little trouble or expense. These devices are the electric sterilizer, electric match, and warm water appliance.

It is unnecessary to call attention to the value of heat for sterilization. This can be secured electrically by either a wet or dry method. A vessel of water may be kept at the boiling point either by the use of ordinary electric heaters immersed in the vessel, or an electric lamp. An electric soldering iron which is to be had on the market, with its handle re-

moved, or an electric lamp of candle-power varying according to the size of the vessel will keep a large vessel of water at the boiling point. The lamp should be immersed, bulb end down in order to simplify the construction of the appliance. This arrangement assures dryness of the socket and also a convenient method of turning the current on or off. If a short lamp is used such as is usually employed for focusing purposes, and with a green globe, the appliance can be made quite ornamental. If a lamp is used in this manner, a four-candle-power lamp will heat a pint of water to the boiling point and higher candle-power lamps a larger quantity of water.

The usual form of steam sterilizer for dental instruments which is upon the market and which is designed to be heated by a gas jet can be heated by electricity in the following manner: A piece of one-quarter inch asbestos card-board is cut out the size of the bottom of the vessel. Thirty feet of twenty-six gauge "climax" resistance wire is crimped in the cogs of the dental rolls and this having been annealed by the passage of the electric current through it, is spread back and forth upon the asbestos board and bound thereto by means of little staples of the same wire, care being observed that neighboring rows of wire do not contact with one another. A second piece of asbestos card-board of the same size but about twice the thickness is bound to the back of the first piece to prevent the radiation of heat, and also to prevent any accidental short-circuiting of the wire staples. The bottom of the vessel having been covered with a layer of thin mica like that employed

for stove windows, it is then placed upon the wires of the asbestos pad and firmly bound thereto. If the two terminal wires be connected to the one hundred and ten volt circuit, the water of the vessel will be continuously kept at the boiling point. Thirty feet of twenty-six gauge climax resistance wire will give the proper resistance for one hundred and ten volts, and if the same is to be used upon the fifty-two volt current it can be done by connecting one wire to the middle of the thirty feet and the other wire to the two ends. By this arrangement the two halves are thrown in parallel and fifty-two volts will produce about the same heat that one hundred and ten volts produce when the halves are in series.

The second method of electric sterilization is by dry heat. This can be accomplished by using a bath of clean white sand in which the instrument points can be buried. The sand is heated to the proper temperature by a coil of german-silver, or climax resistance wire, arranged on the inner surface of the containing vessel. After a little experimental work, the exact amount of wire to give the proper heat can be arrived at. The varying conditions of voltage, size of vessel, and individual requirements, are so widely different that a fixed size and length of wire cannot be given. Yet to begin with, the dentist for the one hundred and ten volt current, may take twenty-five feet of thirty gauge german-silver wire or about thirty feet of twenty-four gauge climax resistance wire. If for a very small vessel for engine points alone, ten feet of thirty-two gauge climax wire may be used. If for the fifty-two

volt current, about half this length of wire will be necessary.

Another method of obtaining dry heat for sterilization is to construct a small oven of sheet iron and use within it an eighth horse-power Carpenter enamel rheostat for the heating agent. This rheostat will give a fixed heat and the temperature of the oven can be easily varied to suit the requirements by means of a ventilating window at the top. The rheostat should be fixed upon the bottom with the lever projecting through a slot in the front, which is only large enough to allow of the lever being used upon the first two buttons. In this manner the lever can also be used to cut off the current and the opening through the sheet-iron at this place permits the ingress of air for regulating purposes, the regulating shutter being the one above.

WARM WATER.

One of the most pleasing and convenient methods of having a ready supply of warm water for syringe use at the chair is by the use of electricity for this purpose. The author uses an appliance of his own design, a side-view illustration of which is given in Fig. 145. A mahogany block four by ten inches, has at the lower margin a socket for an electric lamp, to receive one of the shortest standard lamps made. Just above this is a bowl of green Venetian glass about the size of a large teacup. This bowl is deeply concaved under its base. This concavity rests upon the lamp as shown. The lamp if a four candle-power will raise the water to about 115 degrees Fahrenheit in the bowl, while that

in the bulb will always be found to be within a very few degrees of blood heat. A higher candle-power lamp will keep the water too warm for practical use. If a bracket is placed above the bowl for the mouth-mirrors, they will be kept warm, and the fogging which is always present upon cold mirrors will be overcome.

The amount of current used by this appliance is so little that the dentist can afford to burn the lamp

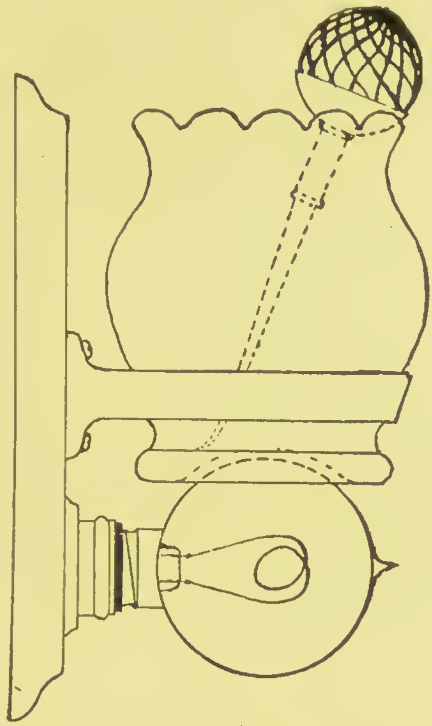

FIG. 145.—CUSTER WARM WATER APPLIANCE.

all day. If rain or filtered water be used in the bowl there will be very little precipitation from the evaporation and the green-glass lamp will give an ornamental effect that is pleasing to the patient.

The Electro Dental Company has a warm and hot-water appliance upon the market which is shown in

figure 146. This appliance is wired to give both warm and hot water. The base is electrically heated and the

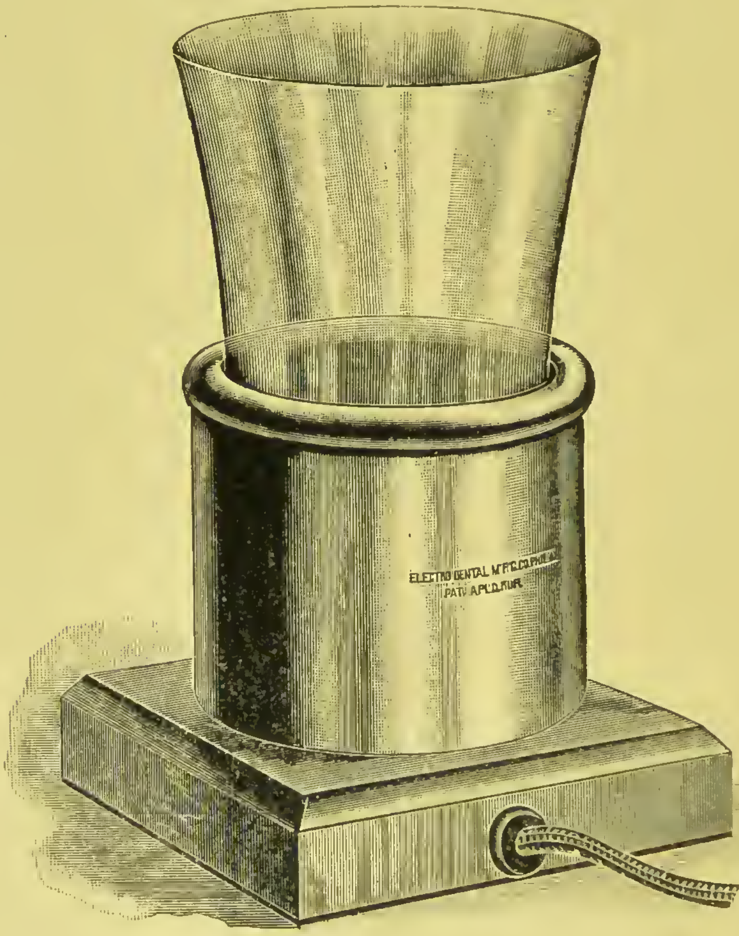

FIG. 146.—ELECTRO DENTAL WATER HEATER.

glass by conduction heats the water within. This is a very simple and neat appliance for the purpose.

THE ELECTRIC MATCH.

The electric match is about the only one that can be relied upon to ignite every time. This instrument

was first exhibited by the author as a part of his electrical cabinet in 1893. It consists of a vulcanite handle with two projecting springs, which are tipped with platinum, or preferably with carbon. The object in using either of these for the tips is that the spark in time would affect other metals which might be used for the purpose, and preference is given to carbon because of its certainty of electrical contact, large spark, and cheapness. If the ends of the wires have small cups one-eighth of an inch in diameter hard soldered thereon, small pieces of one-eighth inch carbon may be cemented in them with a cement made from carbon dust

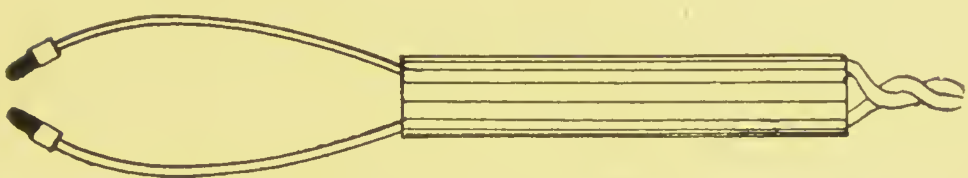

FIG. 147.—AUTHOR'S ELECTRIC MATCH.

and sugar syrup. The metal cups should be fixed at an angle of about forty-five degrees as shown in Fig. 147.

This fixture is hung at any convenient place near the chair by the cord which conducts the current thereto. The resistance for the match to give the proper spark should be about the same as that for an eighth horsepower motor, or for the electric gold annealer, and either one of these can be used for that purpose. By connecting the two wires from the match around the switch which operates either the engine or the annealer, it takes the place of the switch and the spark which would appear at the switch now appears at the match.

The match is operated simply by pressing the springs together till the points touch, when a small arc will be struck. This can be maintained indefinitely by holding the points about an eighth of an inch apart. When through, the arc will be extinguished by releasing the springs.

If it is desired to have a separate resistance for the match, a fifty candle-power lamp, an old small motor rheostat, or a two hundred watt resistance lamp will answer the purpose.

Any number of these matches can be operated from the same resistance by connecting thereto, the necessary requirement being an individual cord running to the place where each match is hung. These, to be convenient, are hung at each gas bracket or valve.

THE ELECTRICAL MELTING OF PLATINUM.

The form of heat employed in all the foregoing except the electric match, is that produced by the resistance of a metal or carbon conductor. The range of heat in these cases was limited by the fusing point of the metal. We now come to a form of heat in which the electric current without any conductor produces the heat. If, with a given pressure, we introduce into the circuit a short piece of metal of moderately high resistance, such as an iron wire, the wire will become heated to a certain degree. If now we substitute for the iron wire, one of german silver, whose electrical resistance is about twice that of iron, the german silver will be raised to about twice the heat of the iron. And so we may go on

increasing the resistance and with that the heat until we have the tremendous heat of the electric arc. In the electric arc we have no metal of any kind to act as a path for the current however high its resistance may be, but we have instead the atmosphere, whose resistance is infinite. The atmosphere is a non-conductor ordinarily and the current in passing through it exhibits itself in the form of heat alone. It is for this reason that the heat of the electric arc is the highest that man can produce. It is so high that its measurement is not an absolute certainty, but it is estimated at about six thousand degrees Fahrenheit.

The electric arc, on a commercial circuit is produced by touching two live terminals together, and then withdrawing them. It requires about forty-five volts to maintain it when once established by prior contact, but to establish it without previous contact requires a pressure of about fifty thousand volts for every inch. The arc having once been established, however, the current continues to flow across the break until the distance becomes too great, when it ceases.

In order to make practical use of this intense heat in dentistry and especially for the fusing of platinum, the scrap of which heretofore was practically worthless except for the small price that was paid for it as scrap, the author in 1893 devised a method of using the electric arc for this purpose. This method can best be used upon the one hundred and ten volt constant current and will be described for such.

The method of 1893 was found to produce a very hard platinum. This was followed up in detail by

the author, and in 1898, he devised a method of producing soft platinum, as soft, indeed, as new platinum. The difference between the two was not due to a different form of heat but to the presence or absence of carbon, while fusing the platinum.

The first method and that for producing hard platinum, is as follows: From eight to twelve ohms' resistance is introduced in the circuit to prevent blowing

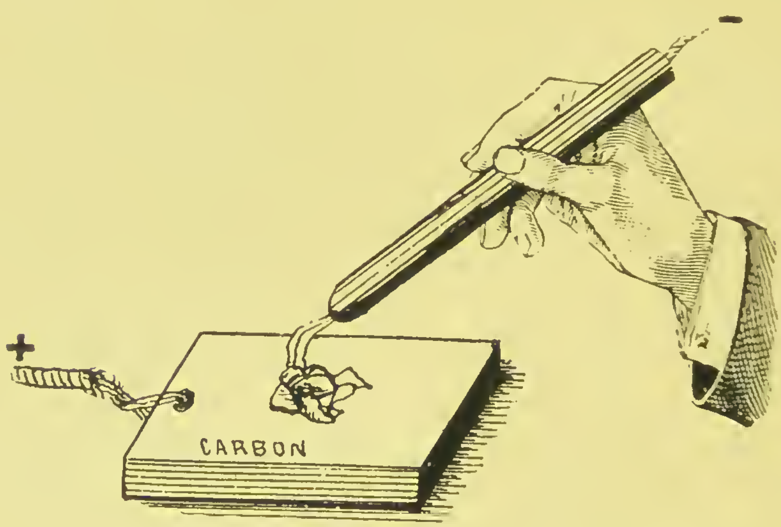

Fig. 148.—Carbon Process for Fusing Platinum.

out the fuses. A special rheostat can be made for this purpose by using about sixty feet of No. 14 german-silver wire. A large size electric oven can also be used as a resistance by connecting one wire to the oven and the other wire to the free main. These wires should be about sixteen or eighteen gauge lamp cord. The two terminals are now tested for polarity by dipping in acidulated water. Bubbles of gas will form on the negative. Attach this terminal to a long electric light carbon

and the other terminal to a piece of carbon battery plate as shown in Fig. 148.

By connecting in this manner the platinum scrap becomes the positive pole which is the hotter of the two. There will be more rapid fusing of the platinum and less noise than if the connections were reversed.

When the connections have been made the platinum scrap is heaped up in the center of the carbon block. The pencil is then brought to touch the platinum and then withdrawn a short distance easily determined by trial. An arc is thus established and the platinum which forms the positive terminal is quickly melted. With twelve ohms' resistance, from six to eight pennyweight can be fused at once, and with eight ohms, nearly an ounce can be fused in a body. By this is meant that the whole mass will be in a melted condition at one time. There is no limit, however, to the amount that can be formed into a single piece. It is not necessary to have the whole mass in a melted state at one time. The edge of it only may be melted and the new metal added while in that condition. The author has melted over ten ounces into one rod in this manner and it was so uniform that it was afterwards drawn out into a fine wire.

The light of the arc is so intense that the eyes should be protected by the use of the darkest-colored glasses that can be obtained.

While the dentist is dealing with one of the most wonderful electrical phenomena in fusing platinum, if he is using the one hundred and ten volt constant cur-

rent there is no danger of more than a slight shock should he accidentally complete the circuit through himself. He can therefore handle the carbon pencil with his bare hands, with impunity.

The platinum which is fused by the foregoing, which we may call the *carbon process,* becomes somewhat harder than new platinum. This is due to its taking up carbon while in the melted state. It appears that platinum is affected in a manner similar to iron by the addition of a small percent. of carbon. It becomes hard and even brittle, according to the amount of carbon. A nugget of platinum which has been instantly fused by the carbon process cannot be detected from new platinum, but if the process be kept up for half a minute, it will show a marked increase in stiffness. It becomes like platino-iridium, and if the process is kept up for some minutes, the platinum becomes brittle and when struck with a hammer may fly to pieces.

The platinum fused by the carbon process is of special value where stiffness and strength are needed. By actual test, with the proper proportion of carbon this platinum possesses almost twice the stiffness of new platinum, and for this reason it makes the best of material for making the pin of a crown, the frame work of a bridge, for the back lining in continuous gum cases, and for strengthening gold fillings.

The second method of fusing platinum whereby it retains its virgin ductility was devised by the author in 1897 and may be called the *lime process.* It is precisely the same as the carbon process except that a block of unslaked lime is used instead of the carbon

plate and a platinum-pointed pencil takes the place of the arc-light pencil. In so doing there is no carbon present and the platinum being unaffected by the lime, appears as soft as new platinum.

The block of lime should be made level on top if the platinum is to be used for a plate, and it should be grooved slightly if to be made into a wire. The lime is not a conductor of electricity as is carbon, it only acts as a receptacle for holding the platinum, whereas the

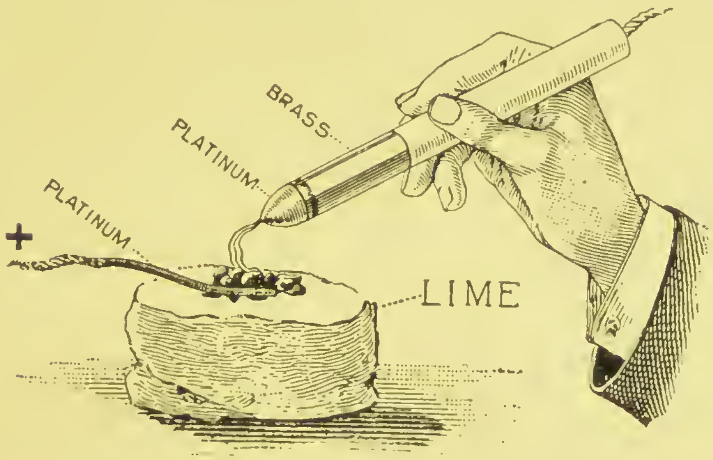

Fig. 149.—Lime Process for Fusing Platinum.

carbon plate is both a conductor and a receptacle. Electrical connection is therefore made by tying a piece of heavy platinum wire or preferably several smaller wires to the end of the positive wire. This makes a platinum terminal for the wire which is laid on the block of lime, and the platinum scrap heaped upon that as shown in Fig. 149. This completes the metallic connection to the platinum scrap. When the scrap has been fused the terminal wire is severed from the nugget.

The platinum-pointed pencil should be made by using a piece of brass rod five-eighths of an inch in diameter and about eight inches long, with a wooden handle thereon. The other end of the rod contains a slot in which a nugget of platinum of at least half an ounce in weight is bound. This nugget while not very large will not fuse because of its negative polarity and of its attachment to the metal rod which conducts the heat away.

When fusing by this method there will be a tendency of the scrap and nugget to unite while either melted or by cohesion, but a little experience will teach one how this can be avoided. A fine carbon pencil, or even the lead from a lead pencil can be used between the platinum point and the scrap to establish the arc, and then withdrawn without measurably affecting the ductility of the platinum.

Platinum which has been fused by the lime process comes out as soft and ductile as new platinum, and will be found to possess all its properties. It is even possible to burn out impurities by this method, so that prolonged melting is also a refining process. This platinum can be used for swaging, for backings, and for inlay matrices, and in fact for all those purposes where soft platinum is indicated.

CHAPTER VIII.

Light.

In all the applications of electric light it has no more fitting place than in the dental office. The nature of the operating room calls for a clean and safe light. The electric light does not rob the air of its oxygen and it does not vitiate it with the products of combustion. An electric light can be placed at any convenient point about the chair and in positions where a gas flame would be impractical. A fifty candle-power lamp may be poised within a short distance of the patient, or a two candle-power lamp can be used within the mouth, without danger or discomfort to either patient or the operator. Moreover, the ornamental style in which electric light fixtures are now supplied, permits of many pleasing designs for lighting. An ornamental figure can be made to hold a chain of series lamps, or another figure can be used for holding a large lamp for the chair. While these fixtures are highly useful to the dentist, they are also pleasing to the patient.

It is unnecessary to go into the details of the electric lamp and its construction, further than in a general way. The incandescent lamp consists essentially of a carbon filament enclosed in a glass bulb. In order to produce light, the filament must be raised to a very high heat. If this were done in the atmosphere the carbon

would be consumed. For this reason the filament is enclosed in a glass bulb from which the air has been exhausted. At the small end of the bulb, two pieces of platinum wire are sealed in the glass, to the inner ends of which are attached the two ends of the carbon filament, and to the outer ends two copper wires which are soldered, one to the threaded shell of the base, and the other to the button in the middle. When this is screwed in a socket electrical connection is made with the mains.

Carbon is used for the filament because it will withstand a very high heat when excluded from the air. The filament in a sixteen candle-power, one hundred and ten volt lamp, is about seven inches long, and six-thousandths of an inch in diameter. This has a resistance of about two hundred and twenty ohms, and such a lamp is usually estimated to consume about half an ampere.

The average life of an incandescent lamp is estimated at five hundred hours. If it is used on a current whose voltage does not rise higher than the lamp is intended for it will last much longer than the foregoing estimate. A few moments of over voltage, however, will soon ruin the lamp. During the life of a lamp it is most efficient at first, and gradually diminishes until, if it does not burn out, it becomes worthless because of its increasing resistance and because of the blackening of the inside of the bulb by a deposit of carbon. The lamp gives but little light and consumes so much current comparatively that it should be exchanged.

The miniature lamp is constructed in precisely the same manner as the large ones, except that the whole

proportions are much smaller. This form of lamp when properly mounted makes a mouth lamp, which is one of the most important dental adjuncts.

The electric lamp makes the ideal light for the dental chair. It is an easy matter to poise one at a convenient distance and position from the patient. One of the first lamps upon the market for use as an operating lamp is that made by the S. S. White Company and shown in Fig. 150.

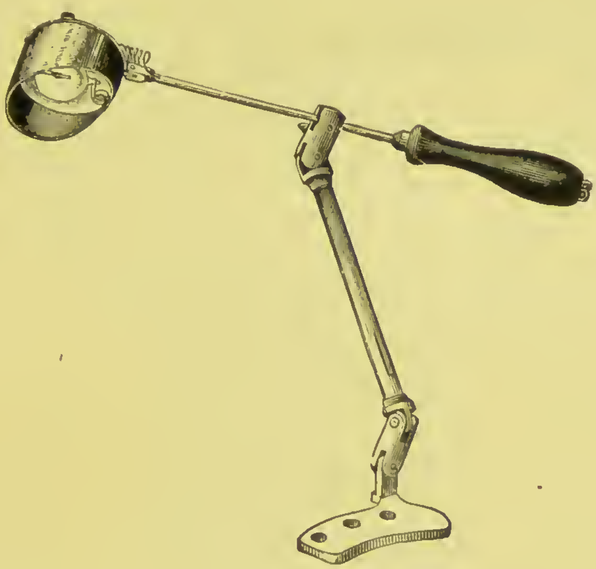

FIG. 150.—S. S. WHITE LIGHT FOR THE HEAD REST.

This is to be attached to the head rest of the chair. A plate is permanently fastened underneath the same and the lamp support is quickly sprung into this by means of a slip joint. The lamp as first supplied with this appliance was one of about four candle-power which was used in series with a larger lamp for resistance. Since that time lamp manufacturers have so improved in their construction that a six or eight candle-power

lamp can be made small enough to be contained in the reflecting hood. The latter lamp needs no extra resistance.

The Victor Electric Company supplies a lamp as shown in Fig. 151, which is to be worn on the head.

FIG. 151.—VICTOR HEAD LAMP.

In some respects this is the ideal lamp. It casts no shadow and the operator has at all times good illumination of the field of operation.

The author has used with considerable satisfaction a focus lamp shown in Fig. 152. This is made by the General Electric Company for stereopticon purposes. It is a fifty candle-power and when mounted on a flexible bracket arm such as may be had at any electrical supply house it is a most convenient and efficient fix-

FIG. 152.—STEREOPTICON LAMP.

ture. A reflecting shade can easily be adjusted to the lamp socket which may be turned at such an angle as to intensify the light and at the same time shade the patient's eyes.

The lamps just referred to are for use as general operating lamps, for dark days, and at the close of the day, and are best operated on commercial currents. We come now to the miniature lamp which is to be used within the mouth and which is for the special purpose of examination and diagnosis, for the detection of pulpless teeth, engorgement of the antrum, of cavities and especially those between the teeth. The extent of many abscesses can often be outlined by this means. The miniature lamp is to be used as often in the day time as upon dark evenings, and may be operated upon either the commercial current with the proper resistance, or by a small battery.

As with the head rest lamp the S. S. White Company was among the first to introduce a lamp for the mouth. This as shown in Fig. 153 consists of a handle with the lamp and reflecting mirror mounted at one end. A feature of this lamp is the convenient device for regulating it. A small rheostat is made a part of the handle whereby the lamp can be easily and quickly adjusted for the strength of current by the simple sliding of the ring seen near the middle of the handle. This lamp may be operated by a few dry cells or upon the commercial current in series with a thirty-two or a fifty candle-power lamp.

The Ritter Dental Manufacturing Company supplies a mouth lamp which is shown in Fig. 154. The lamp

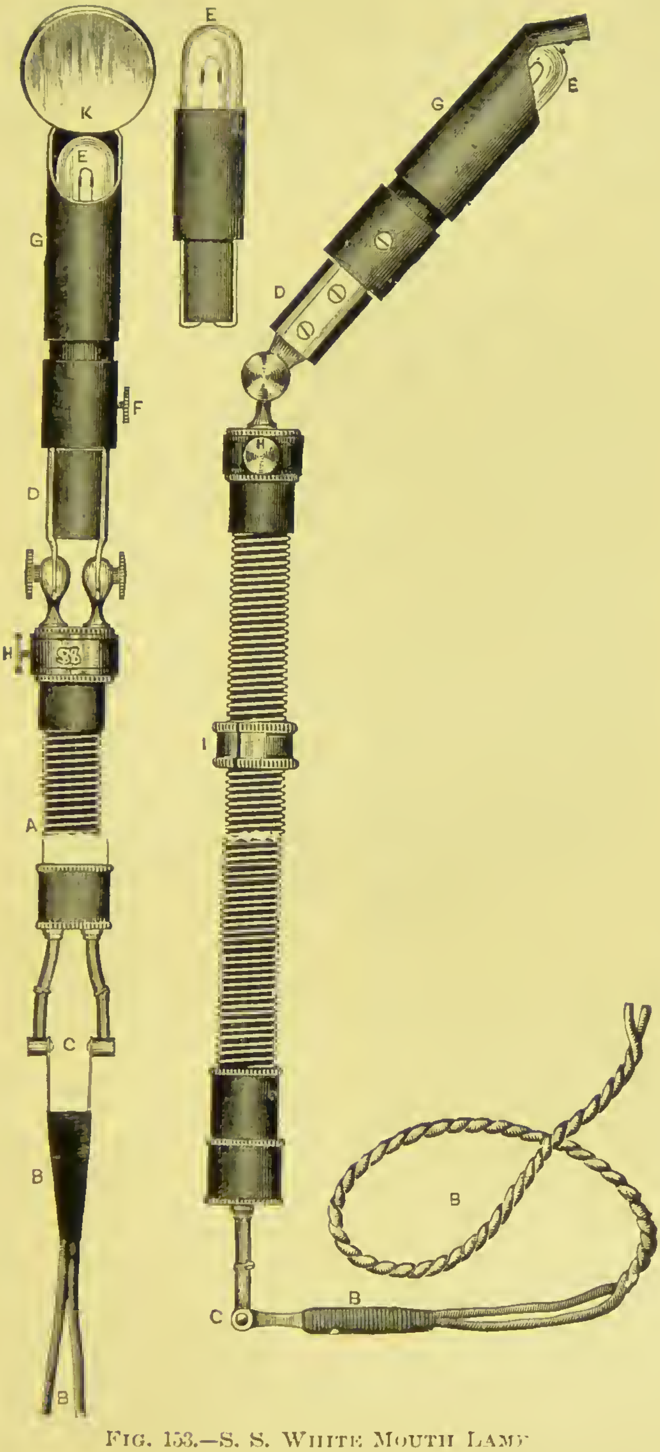

FIG. 153.—S. S. WHITE MOUTH LAMP

is encased in an aluminum handle and shield making it light and clean. This lamp is intended to be operated by dry cells which are encased in the wall cabinet to the left.

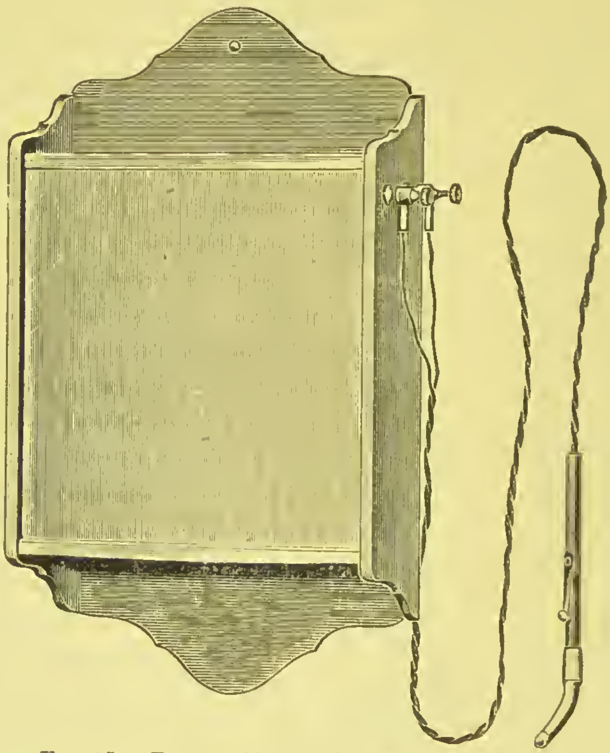

FIG. 154.—RITTER MOUTH LAMP AND CABINET.

The Victor Electric Company also has a mouth lamp upon the market. This has been equipped for both the commercial current and for battery use. The lamp is encased in the end of a long tube which is so constructed that the current cannot reach the patient in case of any accidental grounding of the wires. When it is to be used upon the commercial current a large lamp is used for resistance as shown in Fig. 155.

The mouth lamp not being an every-day necessity, the makers have provided for this by using a current tap base upon the lamp, which makes a complete outfit ready for use when screwed in an ordinary lamp socket.

When the lamp is to be operated by a battery it is supplied with a foot button by which the lamp can be operated intermittently, a convenient feature in many

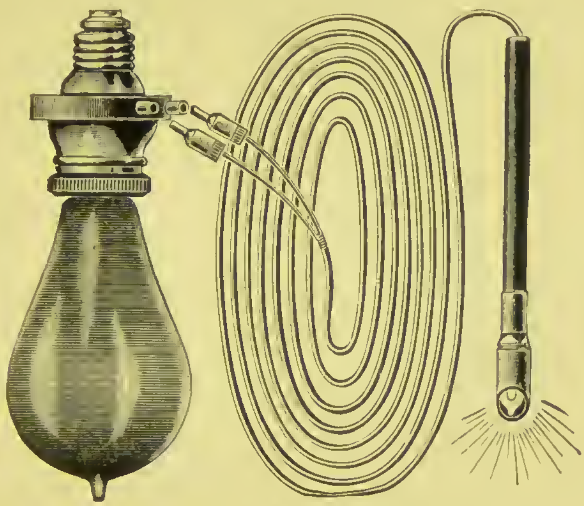

FIG. 155.—VICTOR MOUTH LAMP FOR USE UPON THE COMMERCIAL CURRENT.

instances. It moreover saves considerable current, an item not to be overlooked when the lamp is operated by a battery, for in practice the lamp without a switch is burned as much out of the mouth as it is within it.

The Browning Manufacturing Company supplies a mouth lamp to be operated by a battery giving from four to ten volts. The lamp is enclosed in an aluminum shield and inasmuch as this lamp is not to be used on a commercial current the metal shield will not endanger the patient.

A cautery and root-drier also shown in the illustration are interchangeable with the mouth lamp.

The Garhart Dental Manufacturing Company manufactures a neat little mouth lamp, the invention of Mr. E. E. Werner, which is to be used interchangeably with their root-drier as shown in Figs. 141 and 158. This

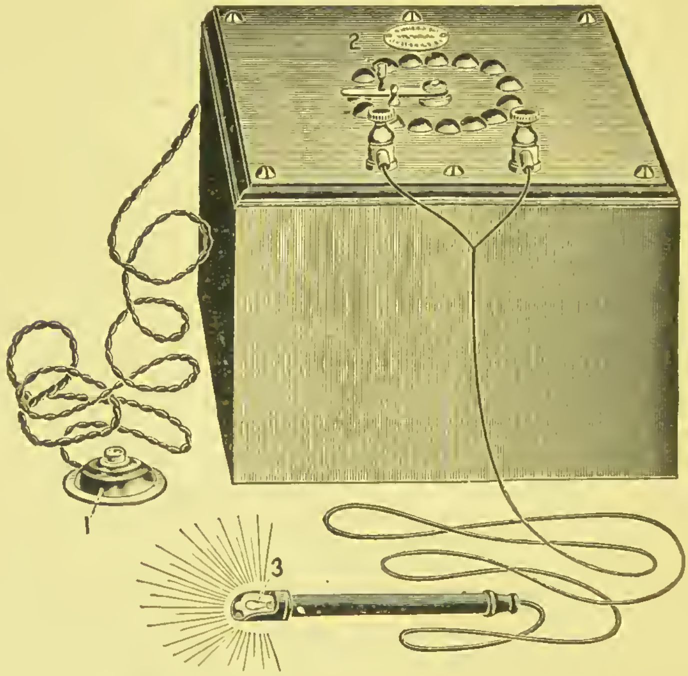

FIG. 156.—VICTOR LAMP OPERATED BY BATTERY.

is designed to be operated on any commercial current used for lighting. The connecting cord which conducts the current to the lamp contains a fine resistance wire which acts in a two-fold manner: While it conducts the current it at the same time gives the proper resistance to cut the current down to the proper strength for the lamp, thus overcoming the necessity of a separate resistance block.

The special feature of encasing a suitable resistance in the conducting cord itself is novel and a most satisfactory method of introducing the neeessary resistance when operating small lamps upon eommercial circuits.

The dentist can easily make his own mouth lamp if he so desires. In selecting a miniature lamp from a catalogue for the purpose of making one, if a one candle-power lamp is desired, and it is to be used in series with a thirty-two candle-power lamp on the one hundred and ten volt current, then the mouth lamp should be

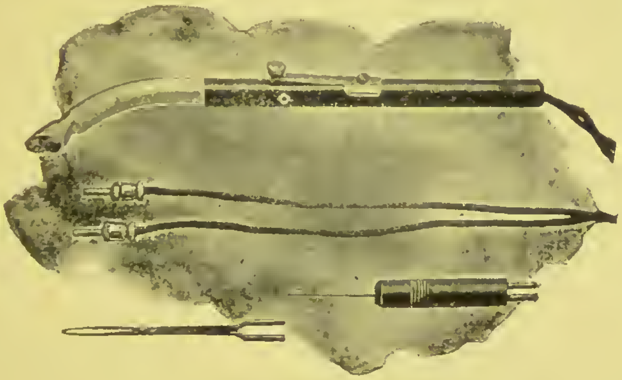

FIG. 157.—BROWNING MOUTH LAMP.

rated to consume one ampere, for the reason that the large lamp which is used for resistance allows that much current to flow and the additional length of filament in the small lamp will cause no appreciable diminution of curent. If the small lamp should be rated to consume half an ampere of current then a sixteen candle-power lamp will give the proper resistance on the one hundred and ten volt current. If the small lamp is to be used on the fifty-five volt current then the resistance lamp should be half the above candle-power, for it should be

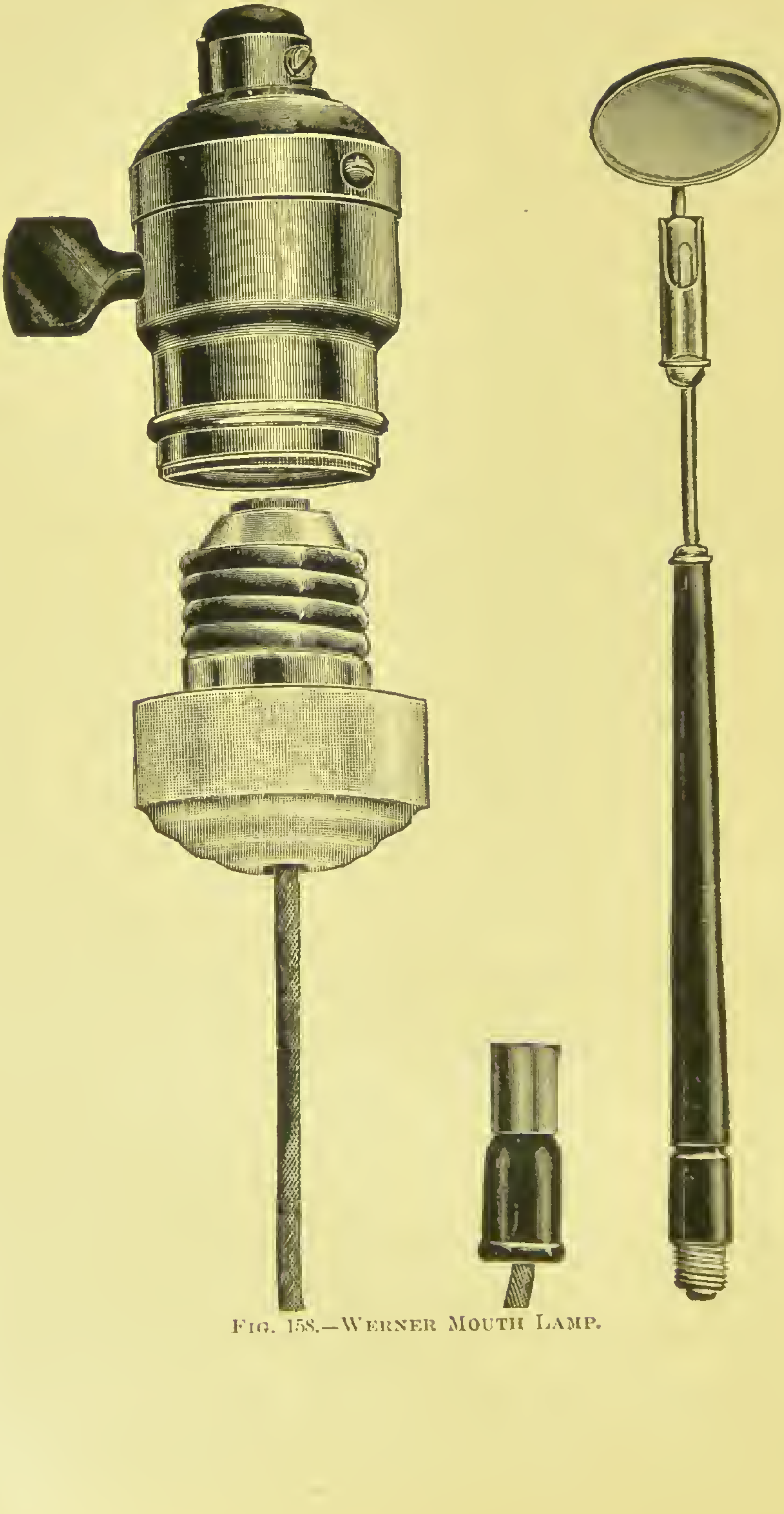

FIG. 158.—WERNER MOUTH LAMP.

borne in mind that as the voltage of lamps of rated candle-power decreases the amperage rises. A sixteen candle-power lamp, for instance, requires about one-half an ampere at one hundred and ten volts, or one ampere at fifty-five volts. To obtain the finest adjustment of the miniature lamp a dimmer socket such as is upon the market can be used in conjunction with it.

The electric bicycle lamp makes a splendid mouth lamp when properly mounted in a handle. This may be operated by the battery that is sold with it or a thirty-two candle-power one hundred and ten volt lamp usually gives the proper resistance when used on the one hundred and ten volt current. A black rubber tube should have a hood vulcanized upon one end of it at an angle of about thirty degrees. This hood should be large enough to enclose half of the lamp. If the hood be lined with a thin layer of plaster of paris it will both reflect the light and serve as a non-conductor. In addition to this the glass of an ordinary mouth mirror can easily be adjusted so as to serve in its usual function. In so doing care must be exercised in insulating the metal back from the wires leading to the lamp for it is almost impossible to use the lamp without allowing the metal parts to come in contact with the cheek or lips of the patient.

When any mouth lamp is to be used upon a commercial current the operator should be always assured as to the insulation of the lamp. It should be encased in a vulcanite handle in which no metal parts are exposed, for it is an easy matter to obtain a ground through the water or gas pipes and especially where a fountain cus-

pidor is attached to the chair. The dentist himself can often convey a painful shock to the patient when using a commercial current without himself being aware of it except by the patient's behavior. The mucous membrane of the mouth is extremely sensitive to electric currents and by reason of its moisture is always ready to make a good contact. Where a fountain cuspidor is fastened to the chair a ground can be established if by nothing else than the column of water in the rubber tube. When operating a foot switch with damp shoes an accidental grounding will be sure to be felt by the patient. It is therefore important to see that the insulation of the mouth lamp, and, indeed, of all electrical instruments used about the mouth is of the very best. The author as a matter of security from any such accidents uses a fiber insulation between the fountain cuspidor and the metal work of the chair. This is sufficient to protect the patient from a ground in touching the metal work of the chair, and for further safety the cuspidor is locked at some distance from the chair arm so that this cannot be directly touched by the patient.

CHAPTER IX.

Electrolysis.

In May, 1800, Nicholson and Carlisle while experimenting with the galvanic current, which at that time was quite new, discovered that if it was passed through a vessel of water the fluid would be decomposed thereby. This phenomenon was taken up by Davy, who not only made further study of it, but turned it to practical use. In 1807 he succeeded in decomposing the so-called "fixed alkalies," whose composition up to that time had been unknown. He obtained metallic potassium from pure potash by electrolysis, and by a similar process soon after, he obtained sodium, barium, strontium, calcium, and magnesium.

At this early date the laws governing electrolysis were noticed, for in 1806 Volta, in referring to the decomposition of water, speaks of the oxygen as appearing at the positive pole, while hydrogen appeared at the negative pole.

The term "electrolysis" has reference to chemical changes that occur when an electric current passes through a conductor of the second class, that is, a conductor which is a chemical compound either in a fused state or in the form of a solution. The essential con-

ditions permitting of electrolytic action are a compound substance and a state of fluidity. Grotthuss supposes that the molecules of a solution are in a constant state of vibration in all possible directions. This condition cannot be present without occasional collisions between the molecules at which time and under certain conditions, as the influence of an electric current, there may be a change of partners. Every molecule has an inherent electrical charge which is divided in itself into positive and negative, residing in their respective groups which are called *ions*. When a difference of potential is sufficiently strong at the electrodes, the ions separate from the molecule in which they are first found and travel toward the pole for which they have an affinity. Those traveling toward the anode are called *anions,* and those traveling toward the kathode are called *kathions*. It is in this manner that a liquid conducts a current and this is illustrated by the traffic over a bridge: Wagons going in one direction carry merchandise of one kind, while those going in the opposite direction carry merchandise of another kind.

Arrhenius in 1887 gave out his theory of the "Electrolytic Dissociation of Ions." He maintained "that the molecules in aqueous solutions are already dissociated into two ions, which are loaded with their respective electric charges"; that "electrolysis does not therefore require the previous splitting of the molecule by the electric current." This seems to be the principal point of difference between the two theories. Arrhenius further stated also, that the passage of a current through an electrolyte is due to the free ions and those molecules

which have not divided themselves into ions, if there are any, take no part in the process. It has long been known that chemically pure water is not an electrolyte, but the addition of the smallest quantity of impurities makes it one. This is accounted for by supposing that the hydrogen and oxygen have not ionized, a condition that is easily produced when an impurity is added. Nor is water the only simple electrolyte, which, when absolutely pure will not conduct a current. Chemically pure, or one hundred per cent., sulphuric acid will not conduct an electric current, and yet when diluted with water till it is about a twenty-five per cent. solution of sulphuric acid in water, it becomes one of the best liquid conductors. The water in this case must therefore be regarded as an agent which is capable of separating the molecule into ions.

There is, therefore, as a first step in electrolysis a selection of partners which have been termed ions. Whether these arrangements are always mutually understood in the molecules or are the result of an electrical disturbance created by the current, is still a matter of speculation. These ions, however, arrange themselves in order, according to their electrical affinities, and move toward their respective electrodes; the anions toward the anode and the kathions toward the kathode. In the formation of the ions the electro-positive elements form one group and the electro-negative form another, making these selections according to the table on the following page of electro-chemical properties by Berzilius.

When the ions have reached the electrodes for which

they started they deliver their electric charges and accumulate at that electrode. If there is any possible affinity between the two, a union is effected, and we have an illustration of what takes place in the well-known process of electroplating; if there is no affinity

Electro-Chemical Properties of Metals.

Positive End.

NAME.	SYMBOL.	NAME.	SYMBOL.
Cæsium	Cs.	Rhodium	R.
Rubidium	Rb.	Platinum	Pt.
Potassium	K.	Iridium	Ir.
Sodium	Na.	Osmium	Os.
Lithium	L.	Gold	Au.
Barium	Ba.	Hydrogen	H.
Strontium	Sr.	Silicium	Si.
Calcium	Ca.	Titanium	Ti.
Magnesium	Mg.	Tantalum	Ta.
Glucinum	Gl.	Tellurium	Te.
Aluminum	Al.	Antimony	Sb.
Zirconium	Zr.	Carbon	C.
Cadmium	Cd.	Boron	B.
Manganese	Mn.	Tungsten	W.
Zinc	Zn.	Molybdenum	Mo.
Iron	Fe.	Vanadium	Va.
Nickel	Ni.	Chromium	Cr.
Cobalt	Co.	Arsenic	As
Cerium	Ce.	Phosphorus	P.
Lead	Pb.	Selenium	Se.
Tin	Sn.	Iodine	I.
Bismuth	Bi.	Bromine	Br.
Uranium	U.	Chlorine	Cl.
Copper	Cu.	Fluorine	F.
Silver	Ag.	Nitrogen	N.
Mercury	Hg.	Sulphur	S.
Palladium	Pd.	Oxygen	O.

Negative End.

the ion appears in the form of a gas or as a precipitate, as the case may be. In the electrolytic decomposition of copper sulphate, for instance, it is first separated into copper, the electro-positive ion, and into sulphion, SO_4, the electro-negative ion. The copper moves toward the negative electrode and the sulphion toward the positive

electrode. If the negative pole is in a condition to receive the copper, and the process is not too vigorous, the copper attaches to the electrode in the form of a metallic precipitate, sufficiently firm to remain and fine enough to receive a polish. The sulphion, on the other hand, upon reaching the positive pole unites with the water forming sulphuric acid and liberating the surplus oxygen, which escapes from the solution in the form of a gas. If the positive electrode is of copper, the sulphuric acid which is formed at this pole unites with the copper, forming copper sulphate, which being soluble in the water is dissolved, thus keeping the electrolytic solution in a state of equilibrium. As fast as copper is taken from the solution and deposited upon the negative electrode, copper is added to the solution by the electrochemical process going on at the other electrode.

Every battery depends for its action upon electrolysis. In this instance the chemical processes that go on in the battery when the external circuit is closed, cause a liberation of the electrical charges of the ions, and we have the manifestation of a current flowing in the external circuit. In battery action, the conditions being favorable, the molecules of the electrolyte dissociate themselves and deliver their electrical charges of their own accord; in simple electrolysis, under the influence of an electric current, we have the ions carrying their charges toward their respective electrodes. While the two processes are identical from an electrolytic point of veiw, we have this marked difference; the one is produced by energy from within and the other by an energy from without.

Electrolysis is an active agent in nature's laboratory. Many of her processes in the life and growth of animal and vegetable organisms, as well as in the reduction of the same, are carried on by electrolysis. Electric currents are developed with the chemic processes and these in turn produce other changes which go on in the building up and in the tearing down of all organic matter.

Electrolysis is of a high value commercially when employed in electroplating, and at the same time if not guarded against it becomes a very destructive agent in our cities. Current easily escapes from the car lines, and, finding good return by way of the water and gas mains, dissolves these at the point of leaving. In this day, when we are surrounded on every side by the commercial applications of electricity, the escape of the fluid into the earth, especially in the cities, and the destructive effect upon the gas and water mains, becomes a perplexing problem for the engineer. This condition is most noticeable in cities operating electric cars, which provide for the return of the current through the rails. This circuit, by bad connections, sometimes offers so much resistance that the current finds a path of less resistance through the water and gas pipes, which may be lying near by. In the course of time these pipes will be found to be badly corroded by the electrolytic action of the current.

While electrolysis may thus become a menace when a heavy electric current is allowed to escape, it however, has electrotherapeutic and commercial uses which make this property of the electric current one of the most useful in medicine and in the arts. All animal

tissues provide the conditions for and are subject to electrolytic action. Albumen is coagulated, water is decomposed into oxygen and hydrogen, and salts are separated into acids and bases. In this process, although in an animal tissue, the laws of electrolysis are the same that operate in the galvanic cell: the acids and oxygen appear at the positive pole and the alkalies and hydrogen appear at the negative pole. This phenomenon is put into practical use by the electrotherapeutist in two ways: One, by the liberation of a nascent salt, by the solution of the electrode itself, and the other, by a decomposition of the tissue with which the electrode is in contact. If the positive electrode be composed of zinc, the chlorine which forms at this pole will attack the zinc, forming zinc chloride, a strong caustic. Or, if the negative electrode be composed of platinum, which is not dissolved by the current, then the underlying tissues undergo decomposition and are destroyed by the agents that form at this pole. Potassium, sodium, and other electro-positive elements that may be contained in the tissues appear at the negative pole and cause destruction of the tissue by their caustic action. While it seems that the loss of tissue in this instance is more largely due to the destructive agency of the products formed, there is also loss of tissue in the first step of the process which gave up these salts.

Electrolysis is a therapeutic agent of unquestioned utility in the treatment of aneurism, cystic tumors, goitre, nasal polypi, naevi, sebaceous tumors, stricture of the urethra, hydrocele, and the like. In some of these lesions this method of treatment gives results

which are even more satisfactory than the older methods of treatment by a surgical operation or by the use of medicinal agents which promote absorption.

Electrolytic treatment has also found applications in dental therapeutics. In 1884 Dr. W. V. B. Ames employed a weak galvanic current in the treatment of pyorrhœa alveolaris. He decomposed the contents of the pockets, getting nascent oxygen and chlorine in addition to the stimulating effect of the current. Medicinal agents were also employed; iodide of potassium when decomposed in the pocket liberated nascent iodine at the seat of pus formation.

The requirements for electrolytic medication do not differ much from those in cataphoresis, as described in the following chapter. The battery or whatever the source of current may be, need not give a pressure of more than twenty-five volts. The rheostat should be one which shall have at least five steps to the volt. A cataphoric rheostat makes an ideal instrument for this purpose. A milliammeter should always be used in the work. This should read as high as forty milliamperes which may be reached in some cases, depending upon the voltage and the area of exposed tissue.

While electrolysis is largely used in the arts, in the manufacture of chemicals, and in metallurgy, its largest field is in electroplating. Nearly every instrument we see about us, every piece of shining metal, and many ornaments which beautify our homes and offices, owe their luster and finish to the plater's bath. Not only this, but nearly every paper that is printed and every book that is published, owes its small cost to the electro-

type. Electroplating has become an industry in which thousands are engaged, and the process has been simplified to such an extent that the amateur can carry on the process at his home.

The dentist has frequent use for an electroplating outfit, and although he may be situated within easy reach of a plating establishment, it is often more satisfactory to do the work himself, provided he has the facilities. The most of his needs are for small work and in his laboratory equipment will always be found instruments and appliances which may be utilized. As a matter of fact but little in the way of appliances is required outside of his laboratory equipment except some of the chemicals employed. He has a lathe and buffers, facilities for heating water and plating solutions, and beyond these nothing is necessary except a few chemicals and the plating baths. The different solutions can be made up and sealed in ordinary glass sealing jars, which not only prevent evaporation when not in use, but by reason of their wide mouths make ideal containing vessels at the time of plating.

While the usual method of electroplating is through the agency of an electric current supplied from without, yet there are metals and solutions in which the simple immersion of the one in the other will cause the precipitation of the metal contained in the solution upon the metal that is immersed. If a piece of clean iron be dipped in a solution of copper sulphate, it will quickly become coated with a covering of copper and in the same manner iron will receive a deposit if dipped in a solution of chloride of bismuth, terchoride of gold,

chloride of platinum, or nitrate of silver. German silver will receive a deposit if dipped in a solution of terchloride of antimony, and also if dipped in gold terchloride, or platinum chloride. Gold terchloride will, when used as a simple solution for immersion, deposit its gold upon nearly all metals, and in like manner platinum chloride will, with almost equal facility, deposit its platinum upon other metals. In these reactions there is a chemical interchange of elements.

Electro-deposition may also be accomplished in a single cell; that is, the article to be plated is made one electrode of the cell. This is illustrated in the ordinary Daniell cell in which the object takes the place of the copper plate.

For commercial purposes, the deposition of metal by means of an electric current supplied from without gives the best results. With the conditions just cited, where the process is principally of a chemical nature, and one which is limited by the local conditions, the deposit is scarcely more than a film, without firmness of adhesion or thickness of body. When an electric current is supplied by a battery, or a dynamo is used, there is an opportunity to control the rate of deposit, to strengthen the adhesion, to modify the fineness of the deposit, and to govern the thickness.

When an electric current is employed, the first essential is that it must be a constant current, such as is derived from a battery, or which is commercially supplied under the name of the Edison or direct current. The dentist can also obtain a current for plating purposes by the use of a small shunt-wound dynamo.

The voltage of the current used in electroplating is comparatively low. It is so low that a few voltaic cells will ordinarily furnish all that is necessary for individual purposes. Gold and copper may be deposited from their solutions with only half a volt's pressure, and even the solutions most difficult to break up require less than eight volts to effect their decomposition. For this reason even the most elaborately equipped plating establishments use dynamos which are wound to give no higher than ten volts. This also covers the resistance of the conducting wires. The dentist's needs are confined to the use of gold, silver, copper, and nickel, and except in the case of the last mentioned, two cells will be all that are necessary. Nickel solutions require from five to six volts' pressure to effect their decomposition and that will necessitate the use of three or four Bunsen cells in series. Or, if the dentist is equipped with the S. S. White battery outfit for operating his electric engine, he can use that for all plating purposes.

The second and most convenient method of obtaining current for electroplating, is by the use of a commercial current, provided it is already established in the office for other purposes. This, of course, should be the constant, or direct current as it is sometimes called. It is usually supplied at one hundred and ten volts' pressure, and in order to obtain a current of low voltage from this for plating purposes, it is necessary to construct some form of shunt rheostat.

The dentist may proceed in this way: Use one sixteen candle-power lamp as a main resistance, and in series with that any electrical instrument or rheostat

which has from five to fifteen ohms' resistance. If this is done as shown in Fig. 159, and two wires are connected, one on either side of the second resistance, a current of from two to five volts will be shunted through the plating circuit. The pressure of the plating current will be inversly proportionate to the resistance of the shunting resistance with which it is in parallel. If an

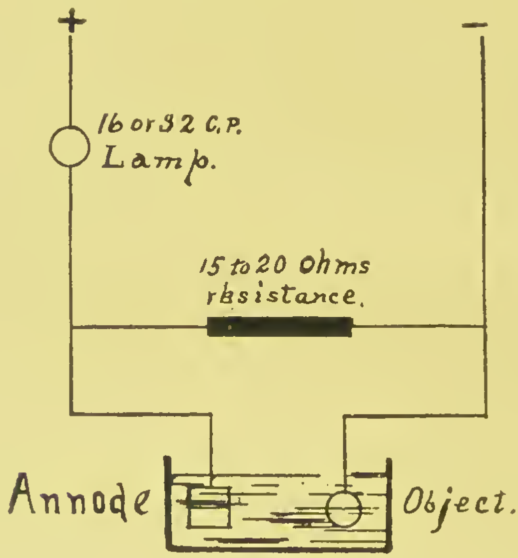

FIG. 159.—DIAGRAMMATIC ARRANGEMENT OF WIRING FOR PLATING ON 110-VOLT CIRCUIT.

electric-light carbon is used as the shunting resistance about half a volts' pressure will be operative in the plating bath, or by the use of a sixteen candle-power lamp as the shunting resistance, as high as fifty volts can be obtained, if necessary. In practice, two or three electric-light carbons, conveniently mounted in the form of a rheostat will be all that is required. Or, the last or second from the last button of any rheostat used for operating a motor or electric oven will give the proper

resistance. A large size electric oven will shunt two volts if closed, or three and one-half volts, if open.

The third method for obtaining a current for electroplating is by the use of a small dynamo as shown in Fig. 160. These, almost as toys, are upon the market for operating small electrical appliances and are de-

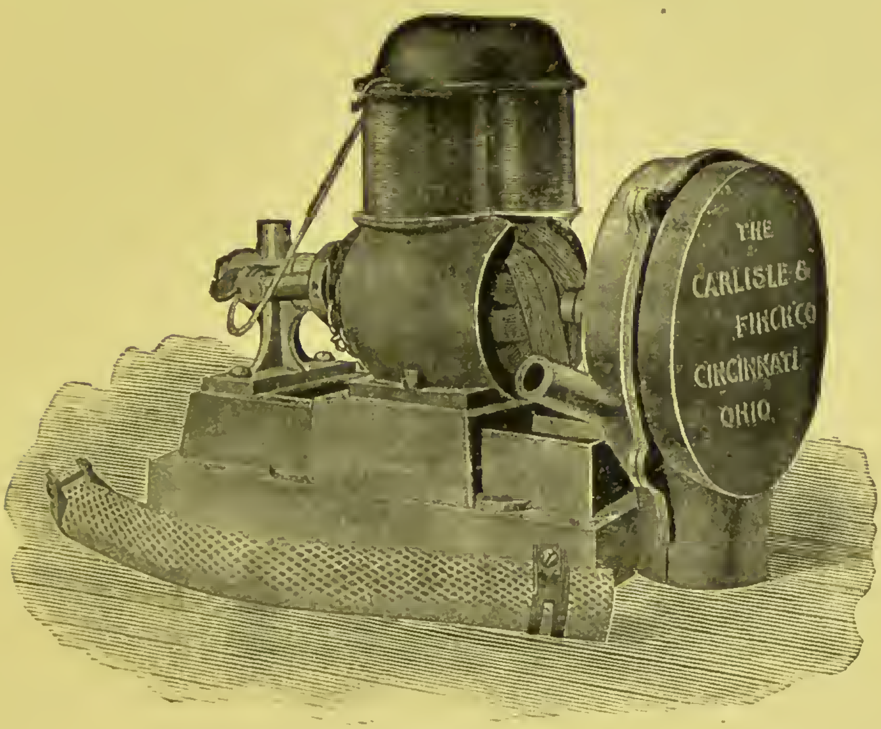

Fig. 160.

signed to be operated by water-power. Complicated as this may seem, it is entirely feasible.

A dynamo for electroplating should be shunt-wound, for the reason that such a dynamo will not change its polarity should a current pass through it from the plating solution in the reverse direction. A series-wound dynamo will reverse its polarity under the conditions

just mentioned, which would be a constant annoyance. Such a dynamo could be used, however, if the operator were observant and employed a pole changer by which the direction of the current through the solution could be quickly reversed should the current be flowing in the wrong direction. Any series-wound dynamo though, can be easily converted into a shunt-wound by changing the connections. A series-wound dynamo or motor has its field and armature connected in series. A wire will be seen running from one of the brushes to the field. If now a new connecting wire be attached to this brush or wire and another be attached to the two binding posts to which the connections were formerly made, uniting them as one, and these two new wires led out to two other binding posts, the dynamo will then be what is known as shunt wound, that is, the field and the armature windings are in parallel. The two systems of wiring can be compared by referring to Figs. 55 and 56 and the subject matter thereon.

Every step in electroplating requires the utmost cleanliness. The least particle of dust or grease will prevent perfect adhesion of the plating. Cleanliness in electroplating means more than ordinary cleanliness. It means an absolute purity of the surface of the metal to be plated. Even handling by the naked hand, however clean, will cause the coating to strip off in time. The surface of the object to be plated must not only be made absolutely clean by mechanical means, but as a last step, chemical processes are necessary before the surface is in condition to receive a coating which will adhere with sufficient tenacity to withstand usage.

In preparing all articles for plating, it should be borne in mind that the finished surface will be the same in point of smoothness that it was before plating. The coat of plating will not be thick enough that when polished it will obliterate scratches of any considerable depth. It is therefore necessary to finish those parts that are to be polished as well before plating as they are expected to be when finished. This can be done upon the dental lathe by the ordinary wheels and buffs used in dressing and polishing vulcanite plates. And, if the dentist enters into electroplating somewhat extensively, he can make excellent buffs by using wooden wheels from two to four inches in diameter and of various thicknesses, upon the rims of which are glued strips of emery cloth of the same width as the wheels. New strips are added from time to time, it only being necessary to glue the ends an inch or more.

When these surfaces that are to be polished have been finished the next step is the chemical preparation of the surface. Iron and steel after being highly polished are passed into a potash bath to remove any oil or grease that may have been contracted during the polishing. This is made by dissolving half a pound of caustic potash in a gallon of water, and is to be used hot. If there has been some delay and a film of oxide has formed upon the surface, this can be removed by immersing for a few minutes in a fifteen per cent. solution of hydrochloric acid. It should then be washed in water and immediately placed in the plating bath.

Copper, nickel, silver, brass, german silver, bronze, aluminum bronze, and several other similar al-

loys are all prepared alike. The buffing having been done, the piece is placed in the potash bath as prescribed for the treatment of iron. It is then removed and briskly scoured with a stiff brush and pumice stone to insure complete removal of the last traces of oil and also to remove the high polish upon the surface. As a final step before transferring to the plating solution the piece is dipped in a solution of cyanide of potassium. This is made up of eight ounces of cyanide of potassium to a gallon of water. It should be kept in an earthenware jar and used cold. When articles are to be gold or silver-plated, the piece may be dipped in a solution of mercuric nitrate, made by acting upon mercury with nitric acid and diluting, just before placing in the plating bath. In doing this a very thin coating of mercury will cover the surface which protects it from oxidation and at the same time produces a more receptive surface for the gold or silver.

When non-metallic objects are to be plated, they have first to have their surfaces made electrical conductors. The most generally adopted plan is the coating of the surface with black lead or graphite. This material, being in a very fine powder, is dusted upon the surface and worked into every inequality. It is the better plan to first coat this with a plate of copper and then treating it as a copper surface it is to be plated with whatever metal is desired.

In making the connections for plating, the object to be plated is to be connected to the negative wire from the battery or dynamo, and an anode of the same

metal used in the plating, connected to the positive wire from the electrical source.

Gold is one of the most easily deposited metals. It will deposit from a terchloride solution by the simple immersion in it of nearly all metals, and if a current is employed, scarcely more than half a volt is necessary to effect deposition. There is no metal used in electroplating that possesses the many properties of gold. This metal has a wide variety of colors and character of deposit, due to the solution from which it is deposited and the strength of current employed. A solution containing from one to five pennyweights of gold to the gallon, will give a fine precipitate of pale yellow color, while a solution very heavy with gold, fifteen pennyweights to the gallon, will yield a deposit of gold of a dark red color. All shades between these can be obtained by modifying the strength of the solution. Then again the strength of the current has much to do with the appearance of the deposit. A weak current of half a volt will produce a deposit of pale, smooth, and closely adherent gold, while a pressure of over five volts will cause a deposit of a dark, coarsely crystalline nature. The latter is not very firmly attached to the metal and is liable to strip in the burnishing or in subsequent use.

There are a great many formulas and methods of preparing a bath for gold plating: Some are to be heated at the time of plating and others are to be used cold. Dr. H. F. Briggs recommends the following: "Take of pure gold thirty grains and digest in aqua regia; evaporate almost but not quite to dryness; dissolve this in twenty ounces of water, then add half ounce of cyan-

ide of potassium." The aqua regia of the formula is composed of three parts of hydrochloric acid and one part of nitric acid. This solution is to be heated to about one hundred and fifty degrees Fahrenheit, at the time of using.

The author has obtained very satisfactory results by using a cold bath of the following formula:

Chloride of gold	30 gr.
Cyanide of potassium	60 gr.
Distilled water	1 pt.

The gold of this formula is the same that is used in photography for toning, and is usually sold in bottles containing fifteen grains each. When the solution is made up it should be kept in a glass fruit-jar, as suggested on page 367.

The object having been prepared for the bath in the manner previously outlined, it is then to be connected to the negative wire from the battery and a sheet of pure gold foil, No. 10, or heavier, suspended from the positive wire from the battery. The foil, which now becomes the anode, should be as large or larger than the object to be plated.

The strength of the current being necessarily very little in depositing gold, a single cell will usually be found to be sufficient. A single Edison-Lelande, or a Bunsen cell will always give ample current for the dentist's use. Open-circuit cells may also be used, and where the operator has only an occasional use for his electroplating outfit, these will probably be the most satisfactory. For the deposition of gold, only one of these, if in good order, and two at most, will be necessary.

Platinum can only be satisfactorily deposited upon copper and its alloys. Tin, iron, or zinc, can only be imperfectly platinized, even after first coating them with copper. One of the difficulties encountered in plating with platinum is the varying condition of the bath, due to the insolubility of the platinum anode. In plating with gold, silver, or copper, the strength of the solution is maintained by about an equal addition of metal dissolved from the anode by the electrolytic process. In platinum and iridium plating, however, the anode is not dissolved and the metal is derived entirely from the solution. The electrolyte is thus being continuously weakened while the deposition is going on. The second difficulty experienced in platinum plating is the ease with which it is deposited from its solutions by the simple immersion in it of some metals to be plated; zinc, iron, and tin reduce it simply by immersion. The facility with which this solution is decomposed causes the same condition that is present when a very heavy electric current is used in plating. It causes the metal to deposit in a loose, black condition, lacking adhesion. It is therefore important in plating with platinum to have the solution rather weak in platinum and use only a feeble current for precipitating it.

The solution generally employed for platinum deposition is the double cyanide of platinum and potassium in distilled water. This is made up in the same manner as the gold solution except that platinum is substituted for the gold. During the action of the bath, free cyanide is formed which should be neutralized by the frequent addition of a little chloride of platinum, prefer-

ably at the close of each operation. If a visible amount of platinum should precipitate, this can be redissolved by the addition of a little soda phosphate.

While with the bath just mentioned the platinic strength can be maintained by the occasional addition of a little fresh platinum chloride, this method is not without objection. For small pieces, such as the dentist may usually wish plated, the chloride bath will be entirely satisfactory, but for large pieces the replenishing of the solution during the process is objectionable. Attempts have been made to use an anode containing platinum in a very fine state of division, in the hope that this might be slightly soluble and thus maintain the platinic strength of the solution. Platinum-black was tried and the experiment proved the correctness of the supposition, but this did not prove to be a practical success. The laboratory experiment and the practical application were quite different conditions. In order to obtain the slightest solution of the platinum, the bath had to be of strong acid reaction. This caused a loose, black, non-adherent precipitate, which was of no value.

An alkaline platinate bath possesses some virtues over the acid bath just described. This is made up as follows:

Platinic hydrate	½ oz.
Caustic potash	2 oz.
Distilled water	1 qt.

Dissolve the potash in the water and then add the platinic hydrate slowly, keeping the solution in motion. A little heat will facilitate the solution.

Not more than two volts should be used in plating with this bath, for a heavier current will cause a non-coherent precipitate. The anode may be a sheet of platinum or a carbon plate not greatly exceeding the surface of the piece being plated. It is always a good plan to plate iron, zinc, and german-silver objects with copper, prior to their receiving the platinum deposit. The strength of this bath can be maintained by the addition of platinum hydroxide. This may be in excess as it will enter into the solution only when it is needed.

Silver, like the two foregoing is easily deposited from its solution but not with such ease, however, as to become a troublesome feature in plating. Its behavior is so much like that of gold that if one were substituted for the other in some of the processes, the results would be equally satisfactory. There is one marked difference in the working of the two; whereas the gold deposit is very easily modified by the strength of the gold solution, deposits of silver do not appear to be affected by the strength of the solution from which they are deposited except when extremes of either density of solution or strength of current are present.

In plating with silver the double cyanide of silver and potassium is most generally employed. This is obtained by dissolving one part of cyanide of silver and ten parts of cyanide of potassium in one hundred parts of water. This may then be diluted to the desired strength, which may be from one half ounce to five ounces of silver to the gallon of water. The silver cyanide may be made by adding a solution of cyanide of potassium to a solution of silver nitrate as long as a pre-

cipitate is formed. The supernatant liquid is then poured off and the precipitate washed.

All silver plating solutions should contain an excess of cyanide of potassium, and this excess should vary according to the metal to receive the plate. This may be largely in excess when depositing upon gold or platinum, but such metals as zinc, copper, and in fact, all those metals which are readily attacked by the cyanide of potassium, require less excess of free cyanide. When copper, zinc and the like are to be plated the work can be facilitated by "quickening" the surface by first washing it with a dilute solution of mercuric nitrate. As a matter of fact if the surfaces of all metals are first quickened, then the cyanide strength of the solution can always be the same and the operator is relieved of any guess work. This method should always be followed where one solution is used for plating different metals.

The quickening solution is made by dissolving an ounce of mercury in a thirty per cent. solution of nitric acid and afterwards diluting with about a gallon of water. This is sometimes called the *mercury dip*. It is well to have a stock solution of this on hand, for it can often be used to advantage in plating with other metals than silver.

The function of free cyanide of potassium is to convert the cyanide of silver into a double cyanide. In the plating process silver cyanide is formed which is insoluble in the solution; free cyanide of potassium being present, it acts upon the silver cyanide, converting it into a double cyanide, which is readily soluble. The absence of free cyanide is shown by the anode turning

a dark color, due to the formation of oxide of silver upon its surface; and an excess of free cyanide is shown by the anode assuming a very white and rough surface, giving it the appearance of a metal having undergone a violent chemical action.

The same rules are to be observed in the strength of current to be employed in silver plating that were laid down in gold plating; a weak current, one scarcely stronger than is necessary to effect decomposition of the solution, will produce a fine, white, closely adherent coating, while a heavy current will cause a loose deposit of dark color, which will not take a good polish. The silver solution should not be exposed to strong light when not in use, owing to the tendency of the silver salt to decompose.

In connecting the wires from the battery the piece to be plated is swung from the negative wire and an anode of silver attached to the positive wire. The anode should be a sheet of perfectly pure silver which has been previously annealed. It should present a surface as large at least as the object plated. If the anode should present less surface than the object being plated, then instead of the plate furnishing sufficient silver to keep the solution at its proper degree of saturation, the solution itself gradually gives up its silver, till it becomes too weak for successful work. It is a good plan, therefore, to always use an anode a little larger than the object to be plated.

The current should always be flowing at the time of placing the piece in the bath. Unless this precaution is observed the free cyanide will act upon the object if

it is a base metal, as is usually the case, dissolving it and contaminating the bath. A silver-plating bath containing copper, iron, or other impurities does not yield a pure white silver precipitate.

Non-metallic objects may be silver-plated by making their surfaces electrically conducting by the use of graphite as pursued in electrotyping. Some years ago electro-deposited silver plates were tried by the profession. The claim of their advocates that such plates were accurately adapted to the model, was certainly correct, but these plates were found not to possess the necessary amount of stiffness for long and practical use, and this system of plate construction soon fell into disuse.

Silver plate is finished much as one would polish a metal plate. As the article comes from the bath, if the plating has been properly done, it presents a white, frosted appearance. For some purposes this is a desirable finish itself. If, however, it is desired to give it a high polish, this can be done by the use of felt wheels, finishing with brushes and buffs, using prepared chalk and rouge. In some pieces a beautiful effect can be obtained by burnishing the raised places and leaving the depressions in their original frosted condition.

Copper, when used in electroplating is of the greatest commercial value. It is not only used as a plating to give a copper finish itself, but is used as a foundation upon which other metals are to be plated. Some metals, platinum for instance, will not adhere to iron, zinc, or tin, with any degree of strength, and yet if these metals are first treated with a copper plate, they

will then receive the platinum with sufficient strength for commercial purposes. In this case the article is treated as if it were copper. Iron is best nickel-plated by first giving it a thin copper plate.

Copper will deposit from some of its solutions by simple immersion. Iron, if dipped in a solution of copper sulphate, will receive a film of copper. It will be observed by this time, however, that those solutions which precipitate metals most easily, as by the simple immersion of another metal in them, are not solutions most easily managed when used for electroplating. The very facility with which they give up their metal is an objection. While it is necessary that a solution should part with its metal when used for electroplating, it is possible to have an extreme, in its being too easily deposited. It is a noticeable fact that in most instances the more difficult it is to decompose a solution the better and more adherent will be the metallic deposit.

All the acid solutions of copper are easily decomposed and their deposits are, as a rule, but feebly adherent. The best results are obtained from alkaline solutions which only part with their metals under the influence of an electric current. An acid solution of copper will require scarcely as much as one volt's pressure to effect its decomposition, whereas an alkaline solution of the same, will require from six to eight volts' pressure. Where it is desirable to deposit a very heavy copper plate it is customary to first subject the piece to an alkaline bath and when it has received a thin coating, to quickly transfer it to an acid bath. In this manner a thick and adherent plate is quickly obtained.

The alkaline copper solution is made up as follows: Copper sulphate is dissolved in hot rain water to about saturation. When this is cold, ammonia water is added till the solution assumes a blue color characteristic of ammonia-sulphate. A precipitate will form during the first stage of the process, but it is afterwards dissolved. Next prepare a solution of cyanide of potassium, half a pound to the quart of water, and add from this until the

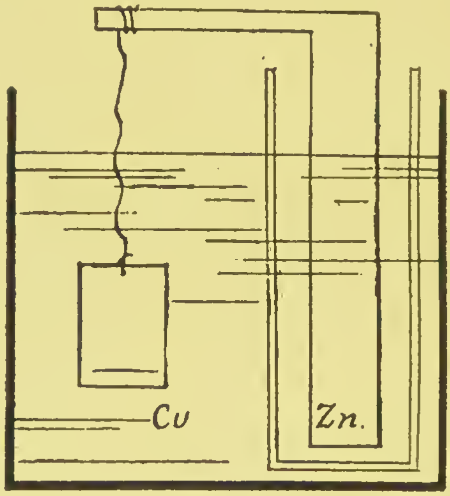

FIG. 161.—SINGLE CELL FOR COPPER PLATING.

blue ammonia-sulphate color disappears. A little of the cyanide should be still added in excess. This solution can be used cold.

The anode of the copper-plating bath should be a sheet of pure copper. This can be obtained under the name of *electrolytic copper*, or, an old copper from a Daniell cell will furnish pure copper.

Owing to the ease with which copper solutions may be decomposed, small articles may be coppered by using a galvanic cell with a porous cup. Within the porous

cup is placed a strip of zinc and a solution of sal ammoniac. The outer vessel contains a saturated solution of copper sulphate. The article to be plated is suspended from the zinc into the copper-sulphate solution, and the process goes on the same as though a galvanic current were derived from an independent cell. This is diagrammatically shown in Fig. 161.

Dr. G. A. Comte has recently suggested a most practical method of making dies for metal work by securing a copper electrotype of the impression and pouring the die metal in the copper form. In doing this a plaster impression is taken and allowed to dry. It is then immersed in melted beeswax till the surface at least is filled with the same, care being observed that there is not an excess filling in the finer lines. In order to facilitate a later step in the process, the sides are built up with wax in just the shape that the die is desired. Graphite is then thoroughly brushed over all the surface of the impression and its side walls. This is then copper plated to about the thickness of an ordinary visiting card. This makes a shell which is an exact duplicate of the surface from which the impression was taken. It is then embedded in sand for support and poured full of the die metal.

The author suggests that an impression taken in modeling composition will take a copper plate without any prior preparation, except as to the coating with graphite. In making the metallic connection to the impression for plating, a thin strip of copper is fastened to the edge of the mold by means of beeswax and this thoroughly covered with graphite.

One can at a glance see the advantage of this method of making a die. It is a perfect reproduction; the surface is much harder than that of a zinc or babbitt-metal die; if a counter-die is cast, there is no danger of melting the copper-covered die. When this method of making a die is used in conjunction with the Parker method of swaging with shot the results are more accurate and the whole process is simplified. Moreover, the necessity of making a core as was formerly done in cases which would not draw from a sand mold is entirely overcome.

In 1888 and 1889 copper amalgam was advocated and was used to some extent as a filling material. While this never came into general use, it however has virtues which make it a useful material in dental practice, not only for the treatment of children's teeth, but for laboratory purposes. This material, being comparatively cheap, may be used for dies and counter dies in crown and bridge work. Copper amalgam was originally made by triturating precipitated copper in mercury in the presence of mercuric nitrate. This was a slow and tedious process and when made in that manner was necessarily expensive. The author, in March, 1889, read a paper before the Mississippi Valley Dental Association describing an electrolytic method of obtaining copper amalgam, which made the process quite simple, and the product very cheap. This was simply the electroplating of mercury with copper. While the two metals have no affinity for one another unless the surface of the copper is first washed with a solution of mercuric nitrate, and even then but feebly, if the copper

in a very fine state of division is presented to the mercury in a nascent condition, as it is in the electrolytic process, then the two will unite, forming a perfect amalgam.

A glass tumbler was used as the containing vessel. The bottom was covered with mercury and a wire led from this to the surface to which the electrical connection was to be made.

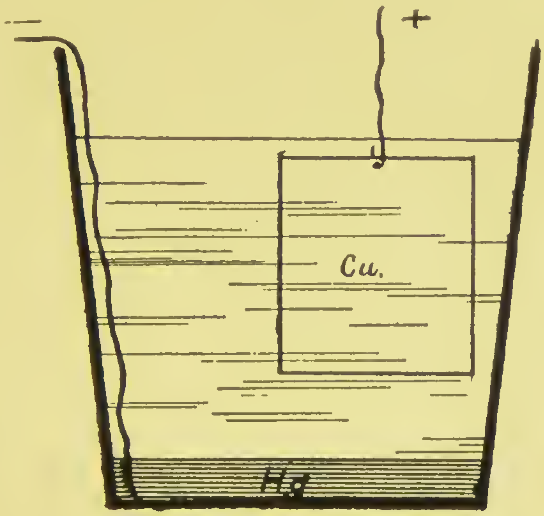

FIG. 162.

A plate of electrolytic copper was suspended above, which formed the anode. The vessel was filled with a solution of chemically pure copper sulphate, and crystals of the same were added in excess to keep up the strength of the solution.

When a weak current was passed through the solution from the copper anode to the mercury, the solution of copper sulphate was decomposed. Sulphur and oxygen, being electro-negative, were liberated at the positive electrode in the form of SO_4, technically known

as sulphion. Hydrogen and copper being electro-positive were liberated at the negative electrode. The hydrogen escapes as a gas, and the copper being in a nascent state, unites with the mercury constituting the cathode in which it appears to assume a crystalline form.

When the mercury has become a thick mass by reason of the copper that it contains, the solution is poured off and the amalgam is transferred to a mortar and triturated for a few minutes. The thick paste is quickly reduced to what again appears to be pure mercury. If now the mercury be taken up in thick chamois skin and manipulated just as the dentist does the amalgam preparatory to filling, the free mercury can be expressed, leaving a thick copper amalgam paste behind. This mass is again and again triturated and the mercury expressed till it becomes too stiff to manage, when it is put away to crystallize. In a day or two this mass will be found to be quite hard. It should then be gently heated in an iron spoon over a flame until mercury appears upon its surface in the form of minute beads. It can then be crushed in a mortar and more mercury obtained from it in the usual manner. When the resulting mass of copper and mercury has been allowed to again crystallize, it is ready for use. It should, however, be put up in the form of little pellets to facilitate its working when used as a filling material.

This material, if it does not contain too much mercury, is very hard when crystallized. It possesses almost a flint-like hardness, which, if the exact proportions of mercury and copper have been obtained, is

such that it can be scarcely affected by a file, and yet after the application of a little heat, the pellet can be easily crushed and made into a plastic mass again.

When a mass of copper amalgam is allowed to harden it appears to undergo a crystallizing process, and when heat is applied the mercury seems to return to its fluid form, thus facilitating the breaking up of the pellet. In this manner the material can be worked over and over again, it being only necessary when the mass works too stiff, to add a globule of mercury to take the place of that lost by evaporation.

Nickel is one of the most widely used metals in electroplating. If we except the value of copper as an electrotyping material, no metal has the commercial importance of nickel when used for electroplating. In the early history of nickel-plating, this metal was used to plate cooking utensils, table-ware, and articles which were subjected to the action of sulphurous fumes and solvent acids. When thus exposed, if the surface were not soon denuded of its nickel coating, it would put on such a dingy appearance as to be very unsightly.

In the course of time it was learned just where it was to be avoided, and it was at the same time learned just where the proper applications were to be made. Its white color, its hardness, and its non-oxidizable nature make it of special value as a protective and beautifying cover for all metals exposed to the air. Iron, brass, copper, and steel, the metals most extensively used, may be readily covered with a coating of nickel and their usefulness, as well as beauty, largely increased.

Iron, the cheapest of metals, by reason of its nickel plate, has taken the place of many of the more expensive metals.

The first attempts at nickel plating were not the most satisfactory. It was not until 1870, when Mr. Adams patented a process for nickel plating, that articles plated with this metal attained a commercial value. The process just referred to, does not pertain so much to a method as it does to the agents employed. Adams used a solution of the double sulphate of nickel and ammonium. This, to give the best results, should be of neither acid nor alkaline reaction, and much stress was laid upon keeping the solution as nearly neutral as possible, by the addition of ammonia, if acid, or by the addition of a little sulphuric acid, if alkaline.

While the double sulphate of nickel and ammonia is the most extensively used, there are other solutions which give excellent results. The double chloride of nickel and ammonium, the acetates of nickel and calcium, and the double cyanide of nickel and potassium are frequently used. The addition of a little boric acid to the sulphate bath will keep it in good condition and prevent the formation of sub-salts; the addition of a little benzoic acid will prevent an uneven deposit of the nickel, and a little common salt will make the solution a better conductor of electricity.

The double sulphate nickel solution is prepared in the following manner: Dissolve about twelve ounces of the double sulphate of nickel and ammonia salt in sufficient hot water to effect a complete solution. This should then be filtered and enough cold water added to

make one gallon. It should then be tested with litmus paper and made neutral by the addition of the neutralizing agent. While it has been recommended that the nickel solution should always be neutral, it has been found that a slightly acid reaction is sometimes to be preferred when plating iron and steel objects.

The Desmur solution which is especially suitable for small articles is made up as follows:

Double sulphate of nickel and ammonium	1 lb.
Bicarbonate of soda	1 oz.
Rain water	6 qts.

The nickel salt is dissolved in the water which should be hot, and the soda added a little at a time, to prevent too violent effervescence.

The anode used in nickel plating is usually pure nickel somewhat larger than the object to be plated. In some cases a little iron is alloyed with the anode. For dental purposes the thin remnant of the larger ones used in plating establishments makes a very desirable anode.

Nickel solutions are not so easily decomposed as are those of most metals. Whereas gold and platinum solutions require scarcely more than half a volt to effect decomposition, nickel solutions require from five to six volts. For the best results as low a voltage as will deposit should be used. A strong current produces a deposit in fine grains and one not susceptible of a high polish. Or it may be one which is liable to strip during or after the finishing.

In nickel plating, as in all electroplating, it is best to have the current turned on before immersing the ob-

ject in the solution. By so doing the article is "struck" by a film of metal the moment of its immersion and any local action is thereby prevented. It is, moreover, a good plan to use a rather high voltage at first, and when the process has been well begun to reduce it. Gold, platinum, silver, and copper plated objects may be taken from the bath for examination from time to time, but nickel-plated objects should not be removed, as the deposit following its second immersion, is liable to strip.

The finishing of all plated articles depends upon the metal used in plating and the uses for which it is intended. Some metals, gold and silver for instance, require but very little, and for some effects, these metals require no finishing at all. If silver has been deposited in good condition, its natural frosted appearance is all that could be desired for some purposes. Nickel, however, is usually polished. The softer metals may be polished by the same methods that are used in the dental laboratory for dentures, or they may be burnished.

Often, good effects can be produced by a combination of both buff polishing and burnishing. Nickel, however, requires a different treatment for obtaining the high polish characteristic of the nickel finish. Nickel-plated articles should be immediately plunged into hot water after removing from the plating bath and then laid away to dry. When dry the article is polished with a buff made of a large number of discs of calico cloth mounted on a mandrel, along with which may be used a little lime or prepared chalk

CHAPTER X.

Cataphoresis.

The term "cataphoresis" from the Greek, meaning to carry along, is used in medicine and dentistry to designate a method of practice in which medicaments are introduced into the tissues by means of an electric current. And, in the course of time as its phenomena became better understood, the term appears to be correct for there is but little question but that medicinal agents under certain conditions can be bodily transferred by the aid of an electric current without suffering electrolytic decomposition, at least in part. This property of the electric current was discovered early in the history of modern electricity. Davy had made known the phenomenon of electrolysis, and Oersted, Amperc, and Faraday were immortalizing their names by their discoveries in electromagnetism. The scientists at that time were almost daily discovering something new. About two years after Faraday's discovery of the electromagnetic property of an electric current in 1831, Fabré-Palaprat employed a weak galvanic current to introduce iodine solutions into the tissues for medicinal treatment. While this method of medication did not receive universal attention, it however embodied all the principles of, and was the foundation of modern cataphoresis.

Dr. W. B. Richardson, of London, in 1859, demonstrated a method of producing anæsthesia by using a sponge saturated with chloroform or other anæsthetics and placing upon this the positive pole of a battery current, the negative pole being in contact with another portion of the body. The method of Doctor Richardson differs from that of Fabré-Palaprat only in the medicinal agent used. The one was for local medicinal treatment and the other was for producing anæsthesia. The technic of both as well as the results obtained were practically the same. The Frenchman had success in his medicinal treatment, and in the same manner about twenty-five years later Doctor Richardson produced local anæsthesia.

Again, after a lapse of another period of like duration, in which time the subject was taken up experimentally by Peterson in this country and Lawrence and Harris in England, and others, Dr. D. F. McGraw contributed two articles before the Minnesota State and local dental societies in 1888 upon the cataphoric use of cocaine for sensitive dentine. A third paper of Doctor McGraw was read upon the same subject the following year at the twenty-fifth anniversary of the Chicago Dental Society by Doctor Thomas E. Weeks, Doctor McGraw not being present. This method had been in practical use to a limited extent by Doctor McGraw and his friends, for Doctor Weeks at the same meeting in a paper of his own upon the treatment of sensitive dentine, speaks of having painlessly removed the pulps of ten teeth after the McGraw method.

Doctor McGraw used a six per cent. solution of co-

caine in alcohol, applying the positive pole to the pledget of cotton containing the medicament. He employed four cells of battery which would have given him about six volts' pressure. The length of time in making an application was from three to nine minutes. In this manner, in not the least particular different from the practical use of cataphoresis of to-day, Doctor McGraw was enabled to anæsthetize the dentine of the tooth.

His theory as to the mode of action was as follows: "The galvanic current acts as a vehicle for conducting the medicinal agents; the cocaine current anæsthetizes the odontoblastic cells and the pulp; the styptic properties of the alcohol act upon the dentinal fibrils, they being of an albuminous nature, causing contraction and increased density and firmness." The theory of the action of cataphoresis is still unsettled, and it may be said that the one promulgated by Doctor McGraw is possibly as nearly correct as any that have been advanced in later days.

Doctor A. C. Westlake contributed an article upon "Electricity; Its Application in Dental Practice," in 1892, in which he touches upon the use of cocaine electrically applied for the treatment of sensitive dentine.

The dental profession, however, did not take up the subject to any extent till it was impressed upon it by Dr. W. J. Morton, of New York, and Dr. Henry W. Gillett, of Newport, Rhode Island, in 1895 and 1896. Doctor Morton had presented two papers upon the subject, one in June, 1895, upon "Cataphoresis and Solutions of H_2O_2 for Bleaching Teeth," and one in Janu-

ary, 1896, upon "Guiacol-Cocaine Cataphoresis and Local Anæsthesia." Both of these agents were to be cataphorically applied. Doctor Gillett in 1895 presented a paper before the New Jersey Dental Society, and a week later one before the American Dental Association upon "Cataphoresis for Obtunding Sensitive Dentine." Here, for the first time, the dental profession awoke to the possibilities of cataphoresis for the application of medicinal agents, its possibilities in the treatment of sensitive dentine, for the painless removal of live pulps, in fact as a panacea for all that was painful in dentistry.

While the experimenters up to this time had not complained of the difficulties attending the process from an electrical point of view, it seemed that for the use of the current upon sensitive dentine provision must be made for a very gradual increase in its strength, not by jumps of a cell at a time but by the gradual increase of the fraction of a volt. In fact, it was soon learned that the tooth was so sensitive to electricity applied in this manner that it could detect an increase in the pressure of less than one-tenth of a volt. For the purpose of meeting this problem, Mr. G. M. Wheeler devised what he termed a "fractional volt selector." This was simply a shunt rheostat so constructed with a large number of steps that the increase from step to step would not produce a shock that would be painful to the patient. This is shown in Fig. 163.

The introduction of this appliance supported by the wonderful claims for cataphoresis made by Doctors

Morton and Gillett marked the beginning of the cataphoric wave in dentistry.

From the very beginning of the practical application of electricity for cataphoric purposes, a variety of theories have been set forth which attempted to explain

FIG. 163.—WHEELER FRACTIONAL VOLT SELECTOR.

the exact nature of the phenomenon. And, even at this day, there appears to be no unanimity of theory as to the precise method of action, in spite of the fact that it has been shown that medicinal agents can be diffused into a porous and electrically conducting substance in a state which appears both in a chemical respect and in its therapeutic effect upon animal tissues to be unchanged. There are two principal theories, namely,

osmosis and electrolysis. Dr. Weston A. Price credits a third theory, "The Polarization of the Tissue, Producing an Inhibition of Sensory Impulse," with consideration. But we believe this has rather a far-fetched relation to cataphoresis. As a matter of fact it has none; for cataphoresis strictly means to carry along as a stream carries a chip. The polarization of the tissue, little as it has been found to be, is not due to any agent carried with the current but to the electric current itself. Nor does clinical experience furnish any substantial proof of the correctness of this theory.

While the phenomena of electrolysis are familiar to most people and the laws governing the changes produced thereby are well understood, there does not seem to be an equally clear conception of osmose, or rather *electrical osmosis* as the electrical process is called. In electrolysis, the decomposition of compound substances, the re-formation of new compounds according to their electrical affinities, and the transfer of elements, follow certain laws that are well established. The splitting up of a compound into groups of the same electrical polarity, the formation of ions, and their travel toward the pole of opposite polarity is a well-known law of electrolysis.

In osmosis without the aid of electricity there is a diffusion of liquids through a membrane or porous partition that goes on as the result of molecular attraction. This is purely a physical force due to the difference in affinities between the two solutions. A vessel with a membranous partition, having a solution of sugar on one side and pure water on the other at the same

height, will undergo a change of level due to the passage of a portion of the pure water into the sugar water compartment. This is simple osmosis.

If now we take a like vessel and fill each compartment to an equal level with the same fluid no change takes place ordinarily. If, however, a current of electricity be passed through the two compartments a portion of the liquid will be carried through the membrane in the direction in which the current is flowing in a manner similar to the osmosis of different liquids. This is electrical osmosis, or cataphoresis.

In electrolysis there is a splitting up of the molecule according to electrical affinities. The electro-positive element or elements forming an ion travel toward the negative pole while the electro-negative travel in the opposite direction. In simple cataphoresis there is a bodily transportation of the solution without decomposition. In dentine cataphoresis, where the conditions are not as favorable as in the case of the vessel with a simple membraneous septum, both processes may be going on at the same time. That is, there may be an electrolytic decomposition of the cocaine in the cavity of the tooth and at the same time a conveyance of some of the cocaine solution unchanged into the dentinal canaliculi.

Doctor Price is of the opinion that the underlying force in cataphoresis is not as just stated, but that the whole process is carried on by the same laws that govern simple electrolysis. He believes that the cocaine is split into ions first, and that the electro-negative ion is the part which enters the dentine and which produces

the anæsthetic effect. If it can be shown that the electro-negative ion of the cocaine solution is an anæsthetic, then the theory of Doctor Price becomes most plausible, and instead of this process being a cataphoric action it is electrolytic, pure and simple.

There is no question but that electrolysis is going on to a large extent; perhaps this is the greater part of the action in the cavity, as is shown by the active liberation of gas and the rapid change to a strong acid reaction as has been shown by Prof. J. S. Cassidy. But even in excess of all this we believe that, following the laws of electrical osmosis, a portion of the cocaine is carried into the dentine without having suffered decomposition. The laws governing electrolysis are fixed and in like manner are those governing osmosis. Electrical osmosis may be carried on through a simple membrane with little loss by electrolytic decomposition, but in semi-porous conductors and with the use of certain agents more or less electrolytic action will also be going on at the same time.

In summing up the two theories, that is of simple electrolysis in which the ion carried into the dentine is the anæsthetic, as promulgated by Doctor Price, and of the carrying in of the cocaine bodily, we must not overlook the fact that both processes are probably going on at the same time; and until it is clearly demonstrated that the electro-negative ion of the cocaine solution is capable of producing the anæsthetic effect which is characteristic of the undivided cocaine solution we may maintain the belief that the anæsthetic effect, after

all, is due to electrical osmosis or cataphoresis, as it has been termed.

The electrical considerations which enter into a successful application of cataphoresis for the relief of sensitive dentine are somewhat complex, and it may be said that there is no process in dental practice in which final success depends so much upon the precise carrying out of every little detail as in cataphoresis. The slipping of a clamp, the leakage of the rubber, the presence of an unsuspected filling, a broken connection and many other little things, which of themselves may be so slight as to escape notice unless the operator is awake to the full importance of every detail, will cause a failure in the end.

Since in cataphoresis there must be an actual conveyance of the medicinal agent, the current must flow in one direction. It may be continuous, pulsating or interrupted, but so long as it flows in one direction when in motion, the result will be the same, and a suitable agent will be carried with it. It has long been observed, however, that the more uniform the pressure is maintained on a continuous current or the more gradually it is raised, the less it is felt in its various applications in electrotherapeutics, and in proportion as the pressure varies while it may still be continuous, it will be painful to the patient. It may, therefore, be stated that under steady pressure a weak continuous current is not painful but becomes so when it pulsates. It becomes more so when it is interrupted and still more so when it is reversed in direction. It is for this reason that the interrupted current is used in shocking ma-

chines and that the alternating current is so deadly. Doctor Morton and others prefer the galvanic current partly for the smooth voltage which is characteristic of this current and the small amount of pain accompanying its applications. On the other hand, there are those who claim that the Edison current furnishes a practically uniform voltage. Theoretically the galvanic current gives the more uniform pressure, but those who use it seem to overlook the fact that they annul this virtue of battery power every time they touch the rheostat for increasing the current, as is customary in its application. If we were endeavoring to use a current from a source which would give the least fluctuation of pressure, the thermopile should be used instead of either; for here we have a current not dependent upon a chemical action which is not uniform at all times during the action of galvanic batteries, nor is it dependent upon the fine division of the segments of the commutator of the dynamo-generated current. The current derived from the thermopile is dependent upon the difference in temperature that exists at the opposite ends of the couplets. In the practical operation of this instrument heat is applied upon the inner ends of the couplets and as their temperature rises electromotive force is felt at the terminals. This increases gradually to the limit of the appliance where it steadily remains. Owing to the large mass of metal and its heat-retaining property, the current from the thermopile will be the most uniform in pressure that can be obtained from any source. But, as before stated, this virtue is lost when a rheostat is used for gradually

bringing up the pressure as is the method in the practical application of cataphoresis.

The Edison current is ordinarily supplied at one hundred and ten volts pressure. This does not vary to any great extent at any time. When it does it is usually so slow that the change would not be felt by the patient. In nearly all cities the pressure drops at about five o'clock, owing to the large amount of current consumed at that time in the lighting of the houses and stores. This, however, is a gradual drop and it may take an hour to show a change of two volts. It should not, therefore, be considered a serious objection to the commercial current. There is another condition, however, which entirely forbids the use of a commercial current for cataphoric purposes. Many dental offices in large cities are in office buildings which operate their own plants. This current is used for the light and power of the building. In many cases the elevators are operated from the same plant. In these instances the feed supply has not the reserve to be unaffected by the sudden demand for current necessary to operate the large elevator motors, and while such a current is practically steady for power and lighting purposes, it is unfit for cataphoresis. The pressure will fluctuate to such an extent as to be painfully felt by the patient. In a few instances of city supply, the dentist may be obtaining his current from the same line that supplies a large motor in the neighborhood. In this instance also, the commercial current is unfit for cataphoresis.

Ordinarily, however, the commercial one hundred and ten volt constant current can be satisfactorily em-

ployed for cataphoric purposes, but with certain precautions. When the current used for cataphoresis is what is known as a current in shunt with the main as all such currents should be, the variation in voltage at the poles is in proportion as the cataphoric current is to one hundred and ten. For instance, if the Edison voltage is one hundred and ten, and the cataphoric voltage averages ten during the administration, it would be necessary that the Edison current should vary eleven volts to produce one volt variation in the shunt; or in other words, a variation of five volts, for instance, an unusually large variation in the main, would produce a variation of but half a volt at the cataphoric poles. Such a variation in the main of a commercial current is very unusual, and should it occur, it is scarcely more than takes place when the dentist operates the rheostat for raising the voltage. The cataphoric current can sometimes be increased from one to five volts without being painful to the patient. Altogether the objection to the commercial current on the ground of its unsteady pressure does not appear to be as strong as claimed, and especially if the cataphoric current be a shunt to the main. In appliances of the author's invention as shown in Figs. 165 and 166, the cataphoric current is made a third shunt to the main which gives a current of unusual smoothness.

There is a more important objection to the commercial current than that of its unsteady pressure, and that is the danger of a sudden shock due either to grounding or to crossing of the wires. In many offices a fountain cuspidor is attached to the dental chair. While there

may be no metallic connection between the chair and the water pipes, the column of water in the rubber supply tube furnishes a path of sufficient carrying capacity to supply all the conditions for a good ground. This may not be sufficient to operate a motor or a lamp, but is ample for cataphoric mischief. The author has repeatedly tested and found that under certain conditions and arrangements of connections, it is possible to have nearly the full current pressure operative. It is an easy matter for the patient at the time of an application to touch the metal work of the chair, and should the connections be carelessly made, a severe shock will ensue.

The second source of danger is from the supply current itself. In the three-wire system it is not an uncommon occurrence to accidentally cross or connect the two outer wires together. In so doing the voltage of the cataphoric current is doubled and a patient under administration receives a severe shock. The current to the patient is just twice its original voltage and while it is not a dangerous increase, it is one which should never happen to either patient or operator.

Much has been said of the dangers which might follow the accidental crossing of the power and arc-light wires with the one hundred and ten volt conductors. There is very little danger from this source unless there should be a ground through the patient at the same moment. The high pressure of the other circuit would dissipate itself immediately in the ample outlets of the lower pressure currents. It would be much like trying to raise the pressure of the water in the large mains by injecting into one of the pipes a fine stream under

high pressure. The many outlets that are constantly open on the mains prevent even the slightest rise in pressure from the additional fine stream of water under high pressure. It may be slightly felt in the immediate neighborhood but the rapid dissipation through the many outlets would prevent any general effect.

If the operator will bear these possibilities in mind and insulate his fountain cuspidor from the metal work of the chair by means of fiber bushings, as the author has done, he may with reasonable safety use the one hundred and ten volt current for cataphoresis. His current supply should come directly from the mains and there should not be an intermittent use of large quantities of current in the immediate neighborhood. Nor should he himself be cutting current in or out for the operation of other electrical appliances in his offices: for the supply wires to his office, while heavy enough to carry all the current necessary, usually have sufficient resistance to cause noticeable variation if other appliances are used at the same time.

A much safer method, although not as convenient, is the use of a battery as a source of current. Having gone over the entire ground both as an operator and as an inventor of cataphoric appliances, the author would recommend a battery consisting of about a dozen Leclanché cells, such as are to be found upon the market for operating bells and telephones. Dry cells may be used with some satisfaction, but their short life is an objection which it seems is scarcely balanced by their natural cleanliness. The storage battery is still another source, but unless the operator has other uses for

it the necessary attention scarcely justifies the use of this battery for this purpose. The Leclanché cell first referred to is an open-circuit cell and is not wasting itself when not in use. Its period of action is usually long enough to supply a continuous current for cataphoresis for a sufficient length of time. In practice, cataphoric applications are not usually so frequent or so numerous but that the battery has had time to recuperate between intervals.

The tooth, the enamel, the arrangement of the canaliculi of the dentine, the relation of the pulp, and the position of the negative electrode are considerations, the importance of which cannot be overestimated. These are the foundation of a successful cataphoric operation.

The enamel consists of ninety-seven per cent. of lime salts, which is a non-conductor of electricity and the remaining three per cent. of animal matter is such a small amount that it offers so much resistance as to be practically a non-conductor. This fact that a sound tooth is covered by a non-conductor of electricity has an important bearing upon cataphoric operations and it may have a physiological significance as well.

On the other hand, the dentine is made up of about one-third animal matter which contains water, making it a good conductor of electricity. The matrix of the dentine is almost solid lime structure, and like the enamel is a non-conductor. But within the tubuli which are radially arranged centering at the pulp canal are contained the dentinal fibrils which are made up almost entirely of water. It is these fibrils that we wish to obtund, and fortunately the large percentage of

water makes them good conductors of electricity. When current is applied it follows these canals to the pulp. Herein lies the importance of first enlarging the cavity at its opening as much as possible before applying the current, for the fibrils anastomose so little that the area of anæsthesia will be confined almost entirely to those tubuli whose mouths open into the cavity. It is only in long applications and where the cataphoric effect reaches the pulp that the fibrils supplied to other portions of the crown will become anæsthetized.

The quantity of current that can be used in an operation, the length of time and the pain limit being equal, depends entirely upon the area of exposed dentine. In the first days of dentine cataphoresis widely different reports found their way into print as to the quantity of current used. In one case the operator could scarcely reach more than one-tenth of a milliampere, while in another he reached as high as half a milliampere, and in a few cases, due to the leakage of the rubber, he might register fifty milliamperes. The cause for all this was to be found in the area of exposed dentine, or, as in the last case, an accident. A small exposure of dentine is like a fine wire; it offers more resistance than a large cavity or a thick wire. In the practice of cataphoresis, we must consider the path from the positive pole in the cavity to the negative pole at the sponge to be like a funnel with a small end equal to the area of exposed dentine and the large end the area of sponge upon the face or hand. No more water can flow through the funnel than can pass through the smaller end, and in like manner no more current can flow than

can pass through the exposed tubuli; and at the same voltage the current increases in proportion to the size of the cavity. Dentine which has been denuded of enamel by attrition offers greater resistance than freshly exposed dentine by reason of the filling in of the tubuli.

The position of the negative electrode has much to do with the application of the current. The shorter the distance that this is placed from the tooth under operation, the less voltage will be required to force the current through, and the less will be the variations due to the alleged pulsations of the Edison current. It is always expedient to operate at as low a voltage as possible for reasons that are obvious. After experiment, the author has found that it usually requires about twice the voltage when the sponge is held in the hand as when held upon the cheek. It is, therefore, recommended that the negative pole be placed upon the cheek and held in place by the same appliance which ordinarily holds the rubber dam in place. By so doing, the pressure need seldom exceed fifteen volts and the operator is relieved of the care of holding the negative electrode.

When cataphoresis was first presented to the profession in a practical form by Doctors Morton and Gillett, the instrument shown in Fig. 163 was the one most suitable. As a matter of fact it was designed for the special purpose. This instrument was a secret in its construction at the time, and the author set about to devise a method of obtaining a current from the one hundred and ten volt circuit that could be easily and accurately controlled. Such a current must start from

zero and increase by very small steps, at least ten to the volt, to about twenty volts. The first instrument designed by the author is diagrammatically shown in Fig. 164. It consisted of a rod of fiber on which a No. 34 thread was cut. Into this thread was wound sixty feet of .01 german-silver wire. Just below, a sliding contact shown at A was arranged in such a manner

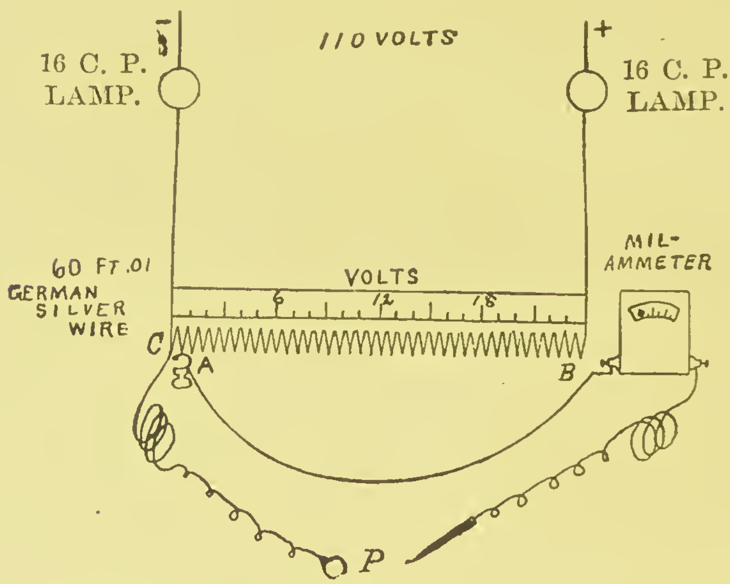

FIG. 164.—DIAGRAMMATIC ILLUSTRATION OF AUTHOR'S SHUNT APPLIANCE FOR CATAPHORESIS.

that it could be easily and gradually moved toward B. Two sixteen candle-power lamps were used for the main resistance, and these were placed one on each side of the resistance coil so that in case of a ground, the current must still go through one lamp whereby the liability of obtaining a dangerous shock was avoided.

When this device is in operation the current enters at the positive wire, traversing the resistance coil B, C,

and leaves at the negative wire. If the movable contact A is in the position shown in the diagram no current will be shunted through the patient P. If, however, A be moved toward B then two paths open and the electric current will divide itself into two, which will be inversely proportionate to the resistance found in each path. In practice it was found that with the above proportion of resistance wire in series with two sixteen candle-power lamps when the brush A was half way between C and B a pressure of twelve volts would be felt at the patient, and that when A was at B, twenty-four volts would be registered in the patient's circuit. In this manner any desired voltage up to twenty-four, or any fraction of a volt thereof could be obtained and shunted through the patient. The fraction of a volt shunted through the patient would depend upon how many turns of wire were necessary to shunt one volt. In this appliance there were 264 turns in the full length of the rod, and there being twenty-four volts shunted in all, there were eleven steps to the volt. In other words the current could be increased one-eleventh of a volt at a step. This strength of increase might be perceptible to the patient if working near the pain limit but it was not a painful increase. In practice it was found that frequently several steps could be taken before the patient would notice the increase.

In the practical operation of cataphoresis it was soon noticed that much of the operator's or assistant's time was consumed in the simple act of slowly turning on the current. It was moreover found that the current was nearly always turned on at the same rate. It then oc-

curred to the author to construct an appliance the same in its electrical details as that just described, but which would be operated by a clock mechanism. This was done as is shown in Fig. 165. The resistance lamps are seen at the top. The rheostat was made by coiling a fine platinum wire upon the periphery of a fiber disc. This disc was mounted upon the minute-hand stem of a small clock. Just below is a cup of mercury into which the platinum wires contact as they pass. In this manner the current was gradually and evenly increased. The increase from step to step was so smooth that the patient could scarcely detect the change. The mercury always made the contact with three or four wires at a time, so that there was never any danger of breaking the circuit while in operation.

It will be observed by an examination of this mechanism that instead of moving a contact lever, the shunt rheostat is itself moved with respect to the contacting point which in this case is a cup of mercury. The effect of this is practically the same as where the contact brush is made the movable part. The two ends of the wire on the disc are connected to wires coming from the resistance lamps. In so doing the shunting resistance is in series with the two lamps with one on either side, a provision made for safety from accidental grounds. Since the resistance coil revolves in the act of turning the current on, provision had to be made for maintaining the two connections in such a manner that they could not possibly be broken, as would be liable to happen if metallic brushes were employed. Instead, therefore, of using brushes for this purpose two copper discs

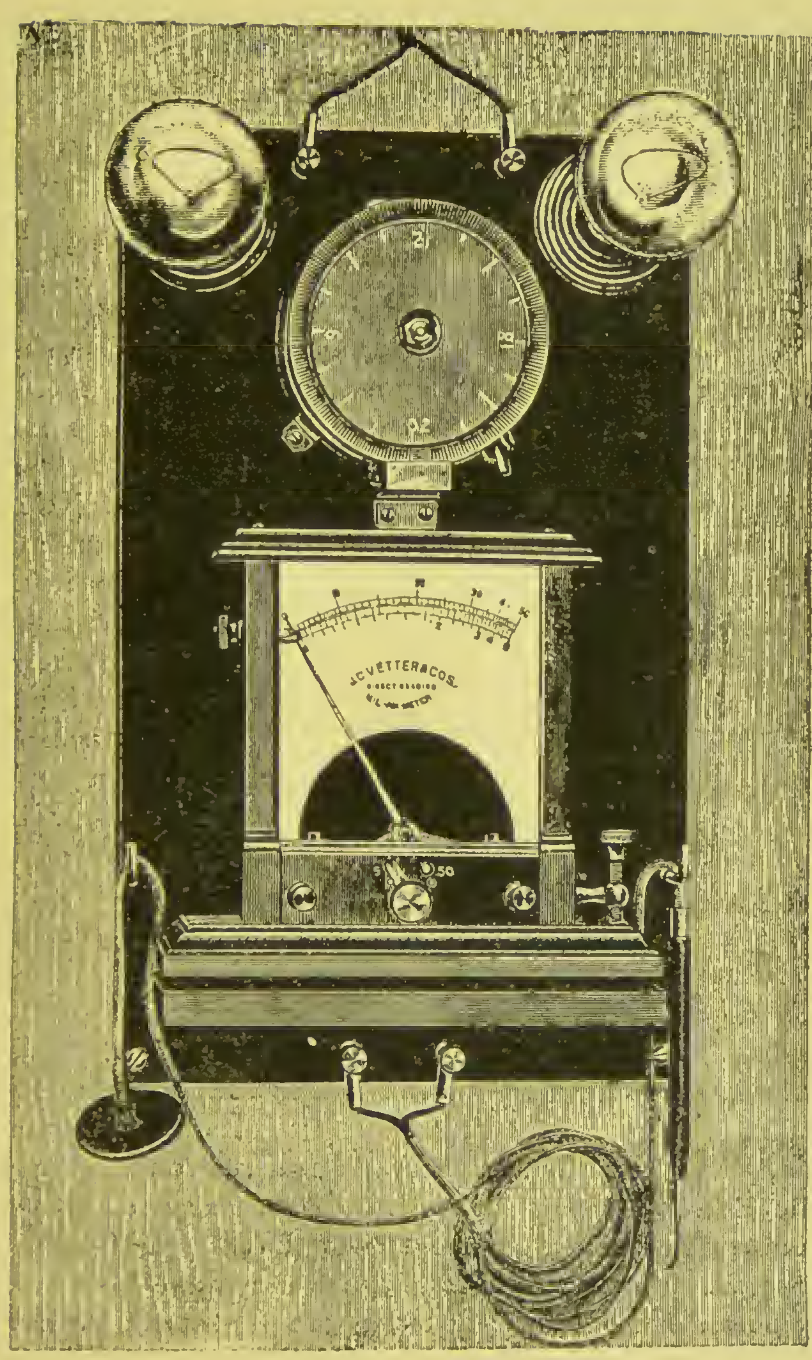

FIG. 165.

were mounted on the same shaft that carried the resistance coil, and these dipped in cups of mercury to which connections were made. The copper discs were first amalgamated by washing in a weak solution of mercuric nitrate. In this manner the resistance coil although movable maintained a reliable connection with the mains.

Beginning at the point marked O, the wheel was revolved towards the left and in so doing the coils on the periphery were made to successively contact with the mercury cup below which represented the movable contact. It required just twenty-four minutes to complete one revolution, a length of time sufficient for cases of sensitive dentine. Half that length of time was usually sufficient. If sixteen candle-power lamps were used, the limit of the shunt current was about twenty volts, and if thirty-two candle-power lamps were used about thirty volts would be the limit.

This instrument was too complicated to be put upon the market and another automatic appliance was devised which was very simple in construction. This as shown in Fig. 166 was made upon the same principle as the foregoing but instead of a clock mechanism for gradually turning on its current, a glass tube containing both the rheostat and the mercury was so inclined that when the mercury was allowed to escape the current would be shunted through the patient's circuit. The rate of flow was regulated by a valve shown at the right. When the index was at five, it indicated the length of time in which the mercury would all run out, and therefore the length of time it would take to reach sixteen

volts, the limit of the rheostat. In operation, the volt glass having been placed upon the upper shelf, the mercury was then in the rheostat compartment. The time

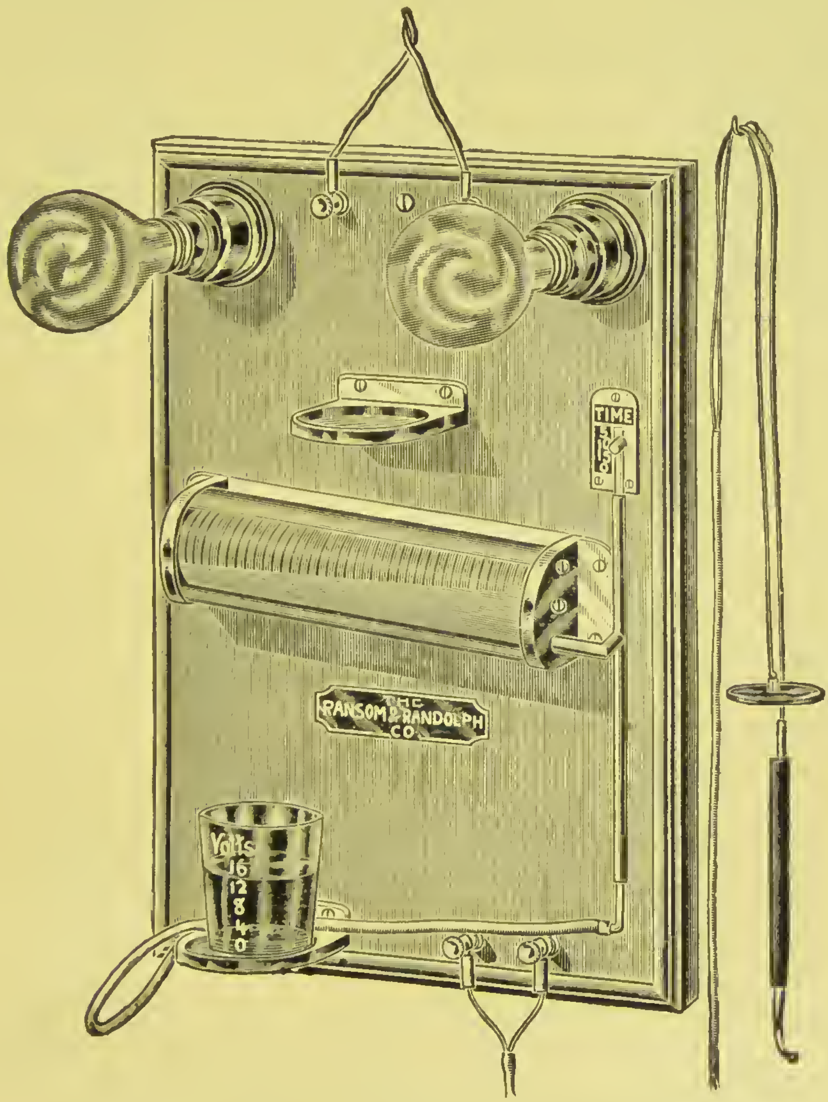

FIG. 166.—AUTHOR'S SELF-OPERATING CATAPHORIC RHEOSTAT.

lever is placed at whatever position the operator, from experience, thinks will be suitable for the case at hand. The volt glass being then placed on the lower shelf, the

mercury flows out of the rheostat chamber at a rate fixed by the timing valve. As the mercury leaves each wire on the rheostat coil the effect is to shunt just that much current through the patient's circuit. In this manner the operator is relieved of the care of turning the current on, for he can set the timing valve and be certain that a uniform increase of voltage will be produced by the mercury flowing out of the rheostat chamber. He can then give his attention to the details of the cavity where it is more needed.

Immediately following the author's description of this method of obtaining a current suitable for cataphoresis from the one hundred and ten volt current, *Dental Review,* May, 1896, the market became filled with a great variety of appliances embodying the shunt principle. The simplest form was the graphite, as shown in Fig. 78. In this the graphite was ground upon a slate base and gave a very high resistance. The brush was to be turned by hand a part usually taken by the assistant.

The Willms rheostat, Fig. 79, when arranged as a shunt rheostat was also largely used for cataphoric purposes, but perhaps the most popular rheostat and cataphoric outfit upon the market is the S. S. White Company's, which is shown in Fig. 167.

This instrument is designed in the form of a wall bracket from which the rheostat is removable. The ammeter, a necessary adjunct, is seen above.

When making a cataphoric operation the rheostat is to be placed upon the operating table so as to be within easy reach of the operator. The rheostat of this appli-

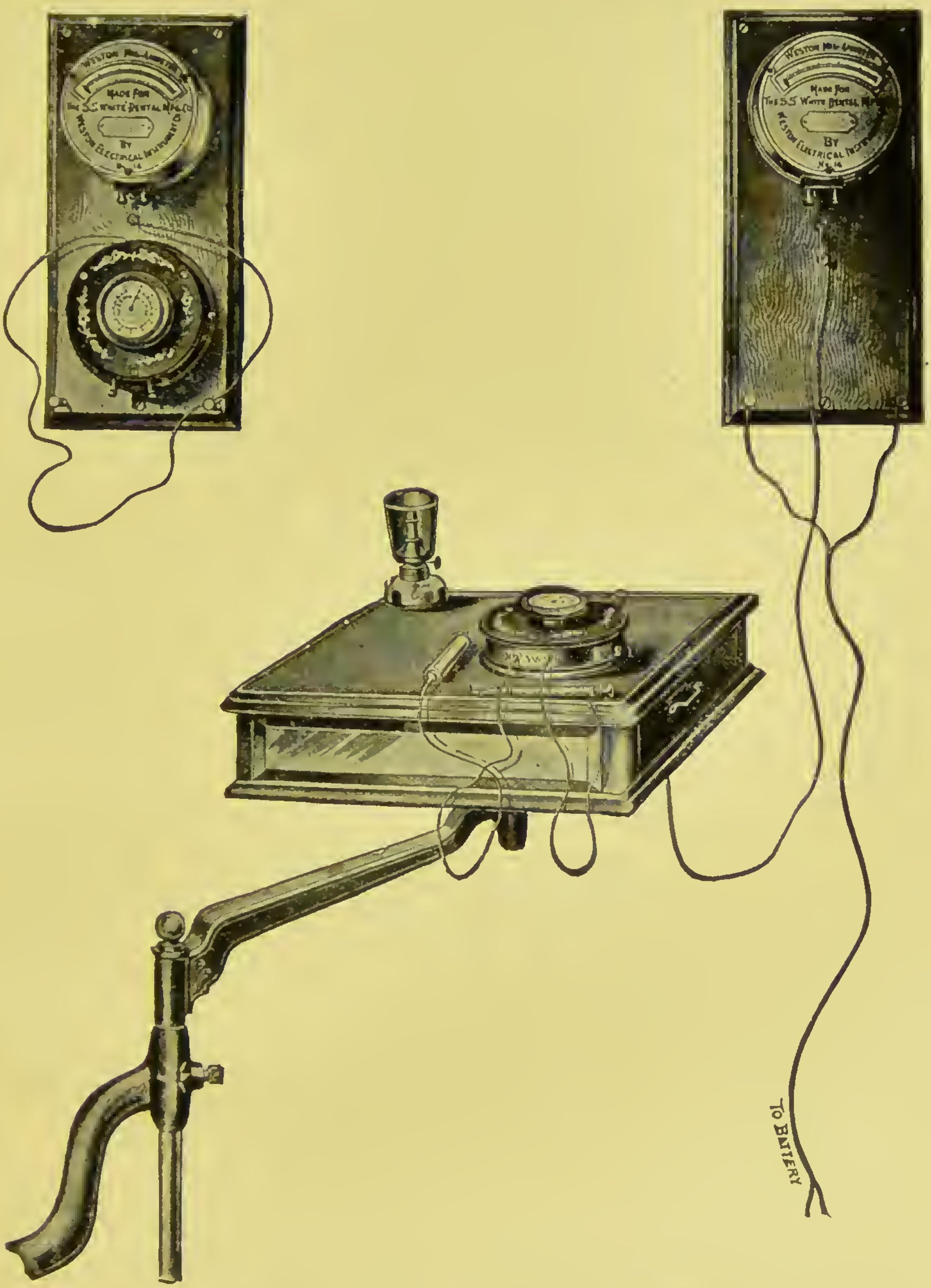

FIG. 167.—S. S. WHITE CATAPHORIC APPLIANCES.

ance is a shunt instrument and is of the graphite variety. This form of rheostat is especially suitable for cataphoric purposes for the reason that there will be no perceptible steps when the current is increased. The rheostat is, moreover, so designed that in turning the regulating wheel an index finger also travels over a scale which is divided into one hundred equal parts. The scale may also be made to read in volts, thus answering a two-fold purpose.

The Ritter Dental Company also supplies a cataphoric appliance for the market. This as shown in

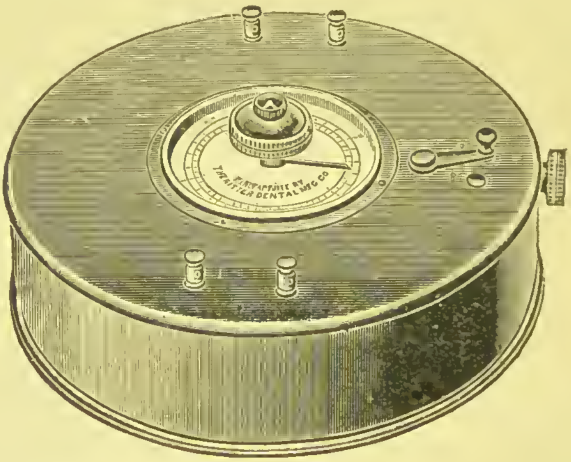

FIG. 168.—RITTER CATAPHORIC RHEOSTAT.

Fig. 168 is somewhat larger than the one just described. It is a shunt rheostat in principal and the steps are imperceptible to the patient. One of the thumb-screws is for turning the current on very slowly, and the other for more rapid movement. While the current cannot be withdrawn from the patient suddenly, the voltage can be quite rapidly reduced, more so than can be done by the thumb-screw which turns the current on. A second

thumb-screw is therefore provided for turning the current off.

Besides the instruments for supplying the current for cataphoresis, there are several adjuncts necessary for a successful administration. The most important of all is an ammeter. This may be so simple as an ordinary compass placed upon a spool of fine wire which is in series with the patient. The author made his first ammeter in this way. A large thread spool was wound full of No. 34 silk-insulated wire and this was fixed upon its side to a wooden base, the two ends of the wire

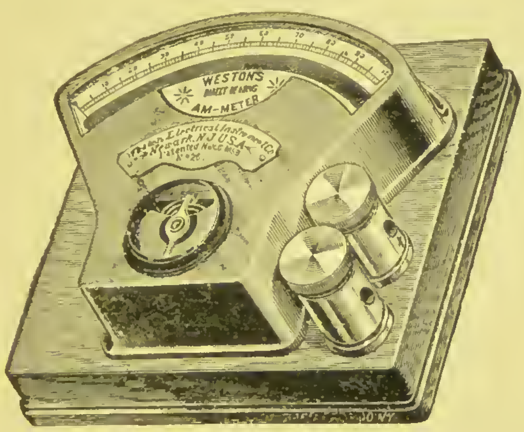

FIG. 169.—WESTON AMMETER.

having been brought out to binding posts. A jeweled compass two inches in diameter was then mounted upon the spool. Such an appliance is ordinarily known as a galvanometer but when wound in more complicated ways and mounted in commercial form it is called an ammeter. Such an instrument is shown in Fig. 169.

The above appliance is one of the standard instruments for electrical measurements. While it differs con-

siderably from the form of galvanometer previously described, the points of difference are the essentials which go to make up a perfect instrument. This instrument is not measurably affected by the earth's magnetism like the ordinary galvanometer, nor is it affected to any extent by the near presence of iron or any electrical instruments that may be in operation. Instead of there being a permanent magnetic needle which swings under the influence of an electromagnet underneath, the moving member of the Weston meter is an electromagnet. This does not become magnetic until current passes through it. The S. S. White appliance in Fig. 167 is fitted out with a special form of Weston ammeter. The scale is in thousandths of an ampere and each thousandth may be read to the one-hundredth part, so delicate is the instrument. This instrument is, moreover, what is known as "dead beat," meaning that the index finger goes at once to the proper reading without the wavering so characteristic of most galvanometers.

The purpose of the ammeter is just the same in a cataphoric administration that the scales and graduates are in the dosage of medicine. It is by this means that the operator tells just how much current is passing and with the element of time he computes the dosage. The two factors, ampere strength of current and the time consumed, determine the depth and quantity of cataphoric infusion. After a little experience the operator can mentally estimate the required time simply by watching the reading of the ammeter. Of course there are conditions that determine the strength of current that should flow in each case. The size of the cavity is

the most important feature which will call for careful judgment on the part of the operator. A large cavity will permit more current to pass than a small one, and only experience and close attention to this factor will enable the dentist to use the exact length of time to infuse to the desired depth. Some cases and even different cases for the same patient will allow of a larger dosage than others.

The ammeter is also valuable for another purpose. It will tell whether there is any leakage of current at the neck of the tooth. While the adjusting of the rubber is always a necessary step, it is still more important to see that it does not leak. If the rubber should leak even so slightly it offers a path for the current of so little resistance comparatively, that the current will nearly all flow through the leak. In the first days of cataphoresis several cases of loss of gum tissue were reported, due to destructive electrolysis from this cause. Such an accident at this day is inexcusable, for by the use of an ammeter the dentist can quickly tell whether or not there is a leakage of current around the tooth. In the average dental case, more than four-tenths of a milliampere can be seldom used without pain. If the ammeter shows more than this, it indicates a leakage. In some cases of leakage the meter may go as high as twenty-five milliamperes, and yet on inspection, a leak cannot be found; but it is there and another adjustment of the rubber should be made.

The amperage that one should expect in each case depends upon the area of exposed dentine, the condition of the cavity, the voltage of the current, and the posi-

tion of the negative electrode. The area of exposed dentine and its relation to the dosage has already been touched upon. The condition of the application in the tooth cavity, however, has not been. This has much to do with the strength of the current flowing. A large proportion of cocaine solution is lost by electrolysis. It takes but a few moments to entirely decompose a drop of the solution under the conditions of dentine cataphoresis. For this reason, unless the cavity is kept flooded with fresh solution, the cotton will quickly become dry, and the resistance be double what it would be if the cotton were kept saturated. The effect of this upon the meter reading will be seen by the index finger dropping back to near the zero mark. Nor is this the only reason why one should keep the cavity flooded with the cocaine; the shock to the patient caused by adding fresh solution to the cotton will be severe and should never occur. Much more time than is necessary is often consumed when the cotton is allowed to become dry.

It will be noticed that there is quite a difference in patients in point of their susceptibility to the electric current. This is so marked that it is a feature meriting consideration. The operator should not be misled by the supposition that where very little current could be used without producing pain, the penetration had been deeper. The idiosyncrasy of the patient will oftentimes not allow of a high voltage, and a longer time must be given at a low voltage, and consequently low amperage, to produce the desired result. Again, even in patients not especially sensitive to an electric current there will be a marked difference in the voltage that

may be used in different cases. A cavity which has been slow of progress, or an abrasion in an aged person, will allow of a much higher voltage than a fresh and rapidly forming cavity in a young person. While a wide range of conditions may be present in cataphoric operations, and it would seem that a volt-meter is not of much value as the pain limit alone determines the pressure that is allowable in each case, one may still be used to advantage. It is an aid in calculating the length of time that will be necessary, a signal in case

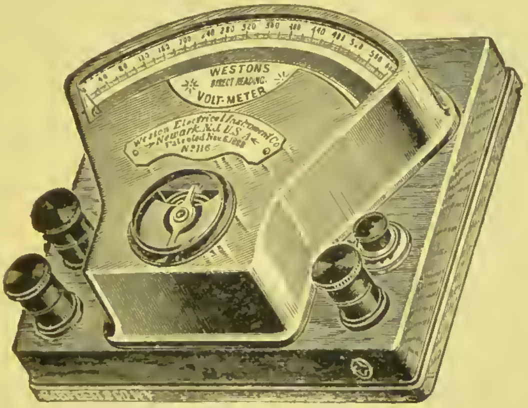

FIG. 170.—WESTON VOLT METER.

of grounded wires, a guide as to the care necessary in maintaining a saturated solution, and an index in turning the current off.

The position of the negative electrode has much to do with the meter reading. If this is placed in the palm of the hand a much higher voltage will be required than when placed upon the cheek. This is due to the resistance of the dry epithelium upon the hand and of the longer path through which the current must travel. Doctor Price has estimated that the average resistance

from the tooth to the hand is about nine thousand ohms, whereas the resistance from the cheek to the tooth is three thousand ohms. The resistance offered by the tooth depends, as previously stated upon the area of exposed dentine, the depth of the cavity, and the condition of the dentine. This ranges all the way from fifteen thousand to one hundred and fifty thousand ohms, the average resistance being about twenty-five thousand ohms.

The positive electrode used in dentine cataphoresis should be of platinum, the object of using this metal for the purpose being that platinum is not affected by the electric current. All the baser metals and some of the noble metals would be dissolved by the current if used for this purpose. In certain cataphoric treatments where it is desirable to apply a nascent metal, or the salt of a metal, the positive electrode is made of that metal with the expectation that it will be dissolved. Zinc and copper are often used as soluble electrodes for this purpose. In dentine cataphoresis it is not desirable to infiltrate the dentinal fibrils with anything but the medicament, and platinum is therefore used in this instance. In the first days of cataphoresis the positive electrode consisted of a platinum point in a rubber-covered handle. It was intended that this be held by either the assistant or by the operator himself. The S. S. White Company supplied an unique instrument for this purpose, shown in Fig. 171. The handle is of rubber and made hollow, but with a metallic connection running throughout its length. A piston plays upon the inside by which the electrode can also be used as a syringe for supplying the cocaine solution.

It soon becomes apparent to the operator, however, that the positive electrode should be fixed in the cavity whenever possible. In cavities very difficult of access

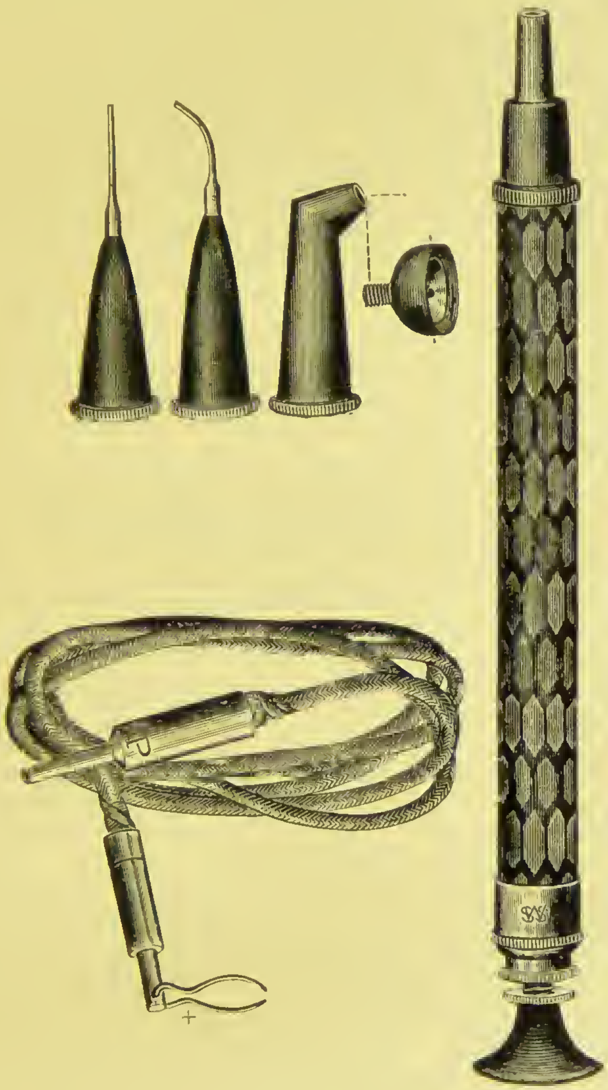

FIG. 171.—S. S. WHITE POSITIVE ELECTRODE.

the hand electrode is the only instrument that can be used. In accessible cavities, however, the author has attached the positive wire to the rubber dam clamp

by means of a little hard rubber clip, which at the same time insulated the wire from the clamp. A similar appliance is shown in Fig. 172.

A much better and quicker method, however, is that first suggested by Dr. Weston A. Price. He attaches a hair-like platinum wire to the positive terminal which is itself very light and flexible. A pellet of cotton the size of a cavity is entwined with the fine platinum wire and the whole packed into the cavity. This will usually be retained by the cavity, and especially if a light tinsel cord is used as the conductor to the same. This cord although very light and flexible has ample carrying capacity for cataphoresis.

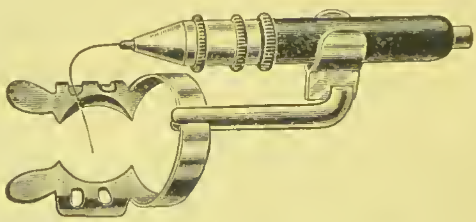

FIG. 172.—McINTOSH ELECTRODE.

When the positive electrode is fixed in the cavity in the above manner, it not only relieves the operator of this tiring detail but allows him freedom to attend to others. Nor can any operator ever hold an electrode by hand as comfortably to the patient as one mechanically fixed in the cavity. The hand electrode must be stiff at the point to enable the operator to use the slight pressure that is necessary. Herein is the objection to the hand electrode. It is impossible even with the closest attention to hold the instrument in the cavity with unvarying pressure throughout the administra-

tion. If he bears too hard and the knob-like point is heavy enough to resist the pressure without bending, the cocaine is squeezed out of the cotton directly under the knob, and the operation will be a failure for the unaccountable reason that cocaine cannot penetrate the tubuli under the instrument point, and the pain effects will be too severe for a complete and successful administration. During the cataphoric application of cocaine for sensitive dentine, the rapid loss of the solution by electrolysis which is going on in the cavity produces a constantly changing resistance, and this, with an unsteady electrode is often sufficient to cause a failure. It is therefore important as one of the first steps to secure the anode in the cavity in such a manner that it will be steadily held either by its own pressure or by some mechanical appliance.

The negative electrode which is to be used upon another part of the body, should be made of a pad of white blotting paper saturated in a solution of common salt, a new one for each patient. Some appliances are fitted out with a hand electrode to be held by the patient. This is objectionable for three reasons: First, the negative pole as has been shown, should be placed as near the positive as possible; second, the thick epithelium of the hand, especially if dry, offers very high electrical resistance; and third, the constantly varying grip of the patient produces slight shocks. If there should be sudden pain at the cavity, the patient most naturally increases the grip upon the hand electrode, which further increases the shock.

The blotting-paper electrodes should be about the

size of a silver dollar. They should be cut from new blotting paper in quantities, soaked in a nearly saturated solution of common salt, and then put away to dry. The appliance for holding the pad should be a vulcanite disc with a recess deep enough to contain a thin sheet of metal and the blotting paper which is placed on top of the same. At the time of operating, the pad is placed in the recess where it will remain after being moistened with water from the syringe. The disc with the blotting paper next to the flesh should then be slipped under the same appliance which ordinarily holds the rubber dam in place upon the cheek, where it will remain throughout the operation. By this arrangement we have cleanliness, the shortest distance between the electrodes, and safety from shocks.

The first and most necessary step is thorough insulation of the tooth by means of the rubber dam. The rubber may leak during the making of a filling, and the operation may not be materially interfered with, but in all cataphoric operations upon dentine absolute insulation of the tooth, and neighboring teeth if included, must be secured. In the adjustment of the rubber for this purpose, it is not well to include too many teeth because of the difficulties of perfect insulation and often of the presence of fillings in them. The rubber should not be pressed down below the enamel except in the region of those cavities which extend to the gum and which are the ones to be operated upon. If a rubber dam clamp is used, it must be seen that it does not crowd down below the enamel, or, if it should, that the cocaine solution does not touch it. If the current should find

a path through the clamp, it would produce a very unpleasant condition of things. The current would pass from the clamp into the dentine without producing anæsthesia, and the operation would on that account be a failure.

Many cataphoric operations have failed, in a painless point of view, by reason of some hidden metal filling or by some unobserved leakage of the solution towards a filling that may be in plain sight. For this reason, all metal fillings which are likely to be reached by the cocaine solution should be first painted with chlora-percha which will act as an electrical insulator.

The second step is the thorough removal of all the enamel that is to be taken away in the preparation of the cavity. This usually causes but little if any pain, and is a necessary step, inasmuch as the cocaine does not penetrate to any extent in a lateral direction. Many operators failed to succeed with cataphoresis by overlooking this step. It was shown in the first part of this chapter that the current enters and follows only those tubuli whose mouths open into the cavity; hence it would be unreasonable to expect no pain when operating upon the margins of a cavity which had not been denuded of enamel, unless the administration had been kept up long enough to reach the pulp and the lateral fibrils have lost their sensation from that source. It may be that in many cases thorough removal of enamel cannot be made before making the cataphoric application, but if it is not, the usual sensitiveness will be found at these margins except in those cases where the cocaine reaches the pulp.

The agents used for dentine cataphoresis are preparations of cocaine. Dr. W. J. Morton in 1896 recommended a solution of guaiacol and cocaine in the following proportions:

Guaiacol	1 drachm.
Cocaine hydrochlorat	5 grains.

This makes about an eight per cent. solution of cocaine. The combination of guaiacol and cocaine was claimed by Doctor Morton to require only one-third the length of time in the administration that cocaine alone would require, but the combination never came into general use, probably due to the odor of the guaiacol.

A combination of electrozone and cocaine was at one time recommended under the impression that the electrozone would aid as a carrier. Experience, however soon demonstrated that after all, cocaine was the active agent and that it itself is a good conductor of electricity without the addition of an agent for that purpose. It quickly manifests an acid reaction, indicating that it has become a good conductor. The question has been raised whether or not any agent to be cataphorically transfused should itself be a conductor. The vehicle in which it is suspended may be, and in this manner the conditions are fulfilled, the vehicle conducting the current and the anæsthetic being carried with the movement of the current. In the author's practice a saturated solution of cocaine in water was the most satisfactory agent or combination of agents. The aim is to convey cocaine into the tubuli and in order to do this cocaine must be present. Inasmuch as there is no danger of producing cocaine poisoning by an overdose when

administered in this manner a saturated solution is always used.

The positive pole is to be placed in the cavity, and the negative upon the cheek. The operator can quickly test for poles by placing the platinum point upon the negative salt water pad. If there is a strong odor of chlorine and a bleaching effect under the point, the poles are correct; if not they must be reversed. When using a battery for power, testing the polarity once will be sufficient. When the one hundred and ten volt current is used, however, owing to the polarity being occasionally reversed, this test should be made before each operation.

During the operation the cavity should be watched, and the cotton kept fully saturated with the solution. This should be added a very little at a time. Usually the amount that can be taken up in a capillary manner by the foil tweezers will be sufficient. If the cotton should be allowed to become dry, the resistance increases while the current decreases; then if the cotton is filled with fresh solution, the sudden lowering of the resistance will cause a severe shock by the inrush of current. The operator can easily tell when the cavity is becoming dry by watching the ammeter. The index finger, which should always be traveling to the right with the increase of voltage, either stands still or drops back.

When beginning the administration of the current, the expression of the patient's face should be the guide as to the pressure that will be allowable. He should be instructed to give a sign upon the first sensation from the current. If an automatic appliance is used

for turning on the current, experience will teach him very quickly the rate that will be allowable in each case. If the current is to be increased by the operator or assistant, the rheostat should be stopped upon the first signal from the patient. After a few seconds' rest the pain subsides and the current can again be increased under the same conditions as before. In this manner, the current is gradually brought up until it ranges from five to fifteen volts for sensitive dentine. The aim throughout should be to increase the voltage as rapidly as the patient will allow, for it is not until the last few minutes that effective infiltration is accomplished. As previously shown, most of the time is consumed in the first part of the operation; a minute at high pressure is equal to several at the beginning of the administration.

While it is necessary to turn the current on very slowly and gradually, turning off the current can be done rather rapidly. The electrodes should not be disconnected or the current turned off by a snap-switch, for that would cause a severe shock, but the rheostat lever should be slowly turned back to the point of beginning. This step may take five or ten seconds to produce no shock.

The length of time consumed in a cataphoric administration upon dentine depends upon the pressure, the condition of the dentine, upon the area of exposed dentine, and upon the depth to which it is desired to penetrate. It would seem that the pressure is controlled entirely by the pain limit, and so it is. Herein lies the secret of shortening the length of

time in cataphoric operations. When the operator fixes both electrodes, and keeps the cavity constantly supplied with fresh solution, and is using an instrument which does not increase the current in perceptible steps, he can reach a high voltage much quicker than when the opposite conditions are present. It should be borne in mind that the depth of penetration in a given length of time is proportionate to the voltage. The last two minutes of the usual administration are more effective than the first six, because of the much higher voltage that is reached at the close of the operation.

It is not within the power of the operator to modify the condition of the dentine, and the length of time, all other things being equal, will be inversely proportionate to the density. The dentine of children and in those cases where the decay has been of rapid progress, will offer but little resistance to the current, and the cocaine will be carried in very quickly; whereas the dense dentine which results from mechanical abrasion, and from old age will be penetrated with difficulty and a longer time will be necessary to effect complete anæsthesia.

The extent of exposed dentine is to some degree a factor in determining the length of time. All things being equal the larger the area of dentine exposed to the current, the more pain will be felt if the pain limit is reached. In practice the operator keeps just within the pain limit and a small cavity will permit of a higher pressure than a large one.

Another reason for the shorter time in the case of small cavities is the less depth necessary for the preparation. As a *rule*, a small cavity usually requires less

anchorage for the filling than a large one and consequently less depth of preparation. Thus in two respects less time will be required for small cavities; the area of exposed dentine is less, permitting of a slightly higher voltage throughout, and the depth of penetration is necessarily less.

In special cases, where it is desired to go to a considerable depth, the length of time will be prolonged; but not, however, in exact proportion to the depth. It seems that, the nerve fibrils having been gradually brought up to a condition of numbness to the electric current either by an advance effect of the anæsthetic or by the toning effect of the current itself, they will allow of much higher voltage than could be tolerated at first.

The average length of time that one should expect to give in dentine cataphoresis with a good rheostat will be about eight minutes. In cases most favorable for a short length of time only five minutes may be necessary, and in case of the opposite conditions as long as twenty minutes may be required. Where a second application is necessary, it is usually found that the voltage can be raised more rapidly than was permissible at the first application.

The foregoing conditions and details have been mainly with reference to cataphoresis for the treatment of sensitive dentine. Besides this, however, the dentist, being equipped with a cataphoric appliance, may use cataphoresis to advantage in the removal of the pulp, lining the pulp canals with a metal or the salt of a metal, the extraction of teeth, opening into the antrum, the excision of the apices of the roots, in bleaching,

and in fact in the majority of instances where an anæsthetic is hypodermically injected, or as in the last instance, where it is desired to force a bleaching agent into the tissue. In cases indicating the removal of a live pulp which is not fully exposed, a cataphoric application of cocaine will oftentimes carry this agent to the apex of the root, and the pulp canal can be opened into and its contents removed without the least expression of pain. In cases in which the pulp is fully exposed a comparatively short administration can be made with equally satisfactory results. It should not be understood, however, that, successful as cataphoresis may be upon sensitive dentine, it is invariably so when used in the removal of the pulp, for there are cases in which for some unaccountable reason repeated applications have only met with partial success. In the majority of pulp cases, however, this method may be used with partial if not complete success. There will nearly always be enough good done to repay the attempt.

Dr. L. P. Bethel in 1896 advocated the use of cataphoresis for the lining of pulp canals with nitrate of silver. This was intended to be used in those root canals which seemed to defy any attempt at entrance with a broach, and sometimes in those canals which could be entered but were exceedingly fine. He says: "Repeated attempts at pumping it into the canals by means of wooden points, broaches, etc., proved unsatisfactory, for the nitrate of silver solution would not go beyond the point of penetration by the broach and the cases most desired to treat were small, branching, or torturous canals, where it was impossible to pass even a broach.

By the aid of cataphoresis, however, the silver nitrate was forced beyond where the broach extended into the small canals, etc., as shown by the specimens here presented. Microscopical examination shows that the nitrate of silver is carried by means of cataphoresis to a greater depth into the tubuli of the dentine, more thoroughly sealing them, than when applied to the surface by ordinary mechanical means."

Nitrate of silver was recommended for the purpose because of its being a conductor of electricity, and possessing the desired antiseptic property. It is to be

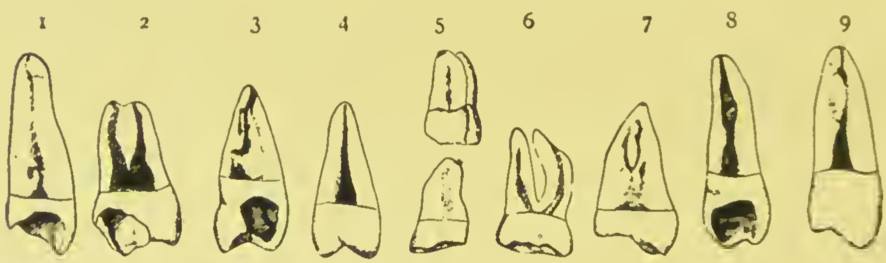

FIG. 173.—PULP CANALS LINED WITH SILVER NITRATE.

used in a forty to a seventy-five per cent. solution. The discoloration of the crown of the tooth was prevented by a thin coating of melted wax.

The silver nitrate in solution is first to be pumped into the root canals as thoroughly as possible and a small pellet of cotton placed at the opening of the pulp canals. The saturated cotton turns first a light green which grows darker until almost black, and serves as an indicator. The time of application will vary according to the condition of the root canal, its size, whether well open, strength of current, and per cent. of solution

used. The higher the per cent. of the solution, the better conductor it becomes, and the quicker the silver is deposited. From one to five minutes seems to be ample time.

After the electrode is removed, the cavity should be wiped out with a strong alkali to neutralize the nitric acid that was formed by electrolysis.

Nitrate of silver used in this manner acts both as a permanent antiseptic lining for the pulp canals and as a powerful germicide at the time of its application. Doctor Bethel states that he has used the method with apparently as good success without any previous medication for the purpose of sterilization.

As stated by the author this method is not to be used in all cases. It is indicated in those instances in which a thorough instrumentation to the apices of the root canals seems impossible, and is of value even in those cases in which the pulp canals have received a thorough cleansing.

Cataphoresis may be used to an advantage in the extraction of teeth, but in so doing a slight modification in the method of administration is necessary. Instead of using a pointed electrode, one must be employed which will not only cover a large area over the roots, but to be effective, it should be applied to both sides at the same time. The S. S. White Company placed such a device upon the market which is shown in Fig. 174. Within the rubber cups at the end is to be placed cotton saturated with the anæsthetic, usually a ten per cent. solution of cocaine. The length of time required is a little less than in dentine cataphoresis.

This method has several advantages over the hypodermic injection of cocaine for this purpose. It is cleanly, and there is very little if any danger of septic poisoning, a patent fault of hypodermic needles. It is almost painless, at least much less so than the needle method. It is comparatively safe from the dangers of cocaine poisoning. There is no danger of bodily entering a vein as sometimes happens when the solution

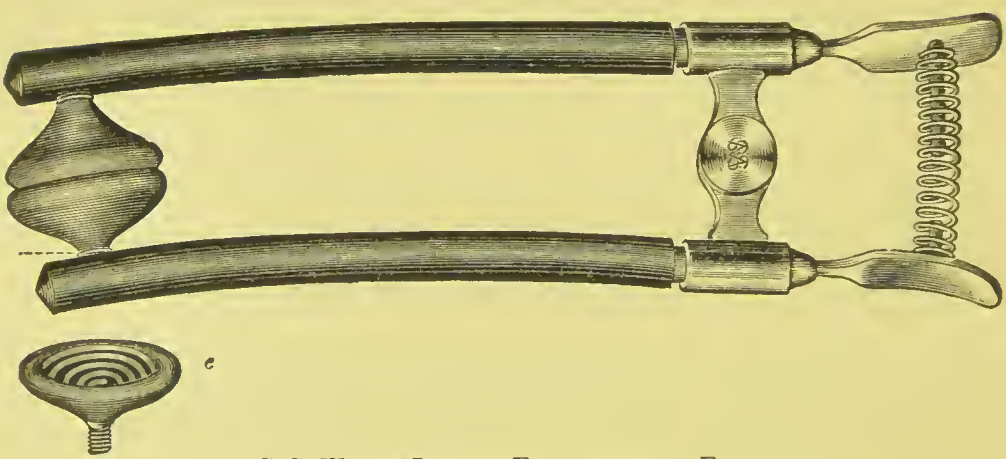

FIG. 174.—S. S. WHITE DUPLEX ELECTRODE FOR EXTRACTION.

is injected with a needle. It has been the opinion of the author ever since the introduction of cocaine, that the majority of the cases of cocaine poisoning when administered by a needle were due to the entrance of the charge into a vein whence it is carried in a concentrated form direct to the heart and lungs where it becomes effective.

A cataphoric application of cocaine is of especial advantage prior to opening into the antrum or the excision of the apex of a root. In both of these cases a topical application of cocaine is frequently sufficient, but when accompanied by cataphoric assistance it be-

comes a most reliable and satisfactory method. It has been the author's practice in these cases to use a double pad of new blotting paper the size of the area to be anæsthetized, saturating this with about a thirty per cent. cocaine solution. This is placed upon the mucous membrane, and an electrode about the size of a dime placed upon this where it is held by the hand throughout the administration. The electrode may be held by the hand in this instance, because the mucous membrane is not so sensitive to the current as the tooth pulp. From three to five minutes is usually sufficient in this class of cases.

At the same time that cataphoresis was introduced for the treatment of sensitive dentine, it was also advocated for use in the bleaching of discolored teeth. Doctor Morton in the *Dental Cosmos* of June, 1895, advocated the use of hydrogen peroxide for this purpose. Following that, various other agents were tried which had formerly been used for the purpose because of their well known bleaching properties. Peroxide of sodium, chloride of lime, and pyrozone especially, were all used cataphorically with equally good results.

In attempting to bleach a tooth in this manner the first step is the preparation of a suitably large opening on the lingual aspect of the tooth. This opening cannot be made too large and especially in the lateral direction. The most perfect cases of bleaching are those in which a groove is cut on the lingual aspect of the tooth which will expose the full width of dentine. The current does not travel underneath the enamel, as has been shown, and for this reason the transverse cut should

be one that will expose all the dentine at its incisive edge.

The second step in the preparation of the tooth is the removal of all or nearly all of the root filling, the object being to provide a path for the current. A pulp canal filled with gutta-percha will offer such a high resistance that it may be almost impossible to start the process.

The instruments and electrodes used in bleaching

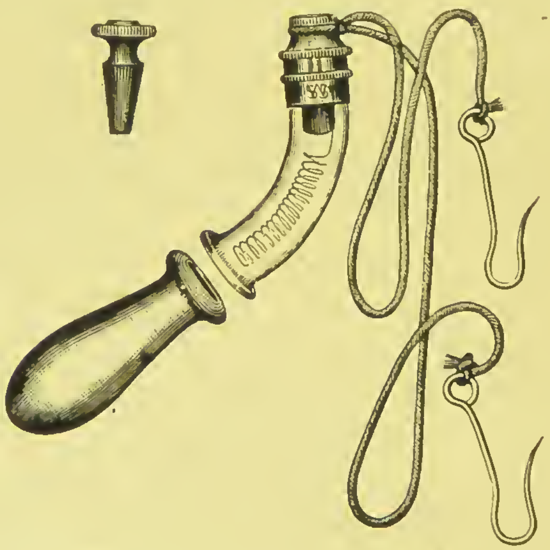

FIG. 175.—HOLLINGSWORTH TUBE ELECTRODE.

have been especially devised for this purpose. The S. S. White Manufacturing Company with its usual enterprise has placed a rather unique set of appliances upon the market for bleaching, the invention of Dr. W. M. Hollingsworth. The first step after the preparation of the transverse groove is the provision for holding the electrode and bleaching agent in position. A rubber nipple shown in Fig. 175 has a hole cut in it of the

usual size for slipping over a tooth. This is then expanded by means of the nipple expander shown in Fig. 176 and slipped over the tooth to be bleached. By a careful movement the expander can be removed, leaving the rubber nipple tightly enclosing the tooth. It is not necessary to slip the nipple more than two-thirds the distance upon the tooth. This being accomplished, the special electrode, also shown in Fig. 175, is then slipped in the open mouth of the nipple.

The next step is that of filling the glass and nipple with the bleaching solution. For this purpose a special syringe called a duplex syringe shown in Fig. 177 is to

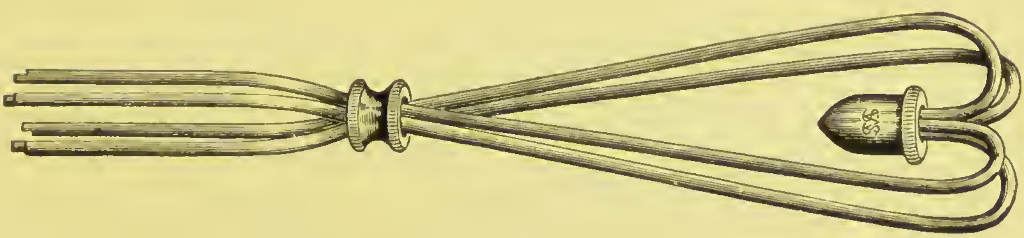

FIG. 176.—NIPPLE EXPANDER.

be used. The fine nozzle communicates with the second bulb. This is filled with the bleaching solution in the usual fashion. When the syringe is fitted into the electrode, the forward bulb being first compressed is allowed to expand. This exhausts the air from the electrode and nipple, and a little pressure upon the rear bulb quickly fills the electrode with the solution. In this manner the electrode is kept constantly filled.

While a solution of sodium peroxide and the usual chlorine liberating agents in solution may be used, preference has been given to pyrozone when used in the Hollingsworth appliances. The ethereal solution of

hydrogen peroxide is not a good conductor of electricity, and it must therefore be converted into an aqueous solution, which is done in the following manner: One part water to two parts of a twenty-five per cent. pyrozone solution are held in an evaporating dish over a flame till the ether has evaporated. This leaves the hydrogen peroxide in an aqueous form and a good conductor of electricity.

The voltage and the amperage that one should expect to obtain in bleaching will vary much more than in dentine anæsthesia, depending upon the condition of the pulp canal and the resistance of the root portion. It

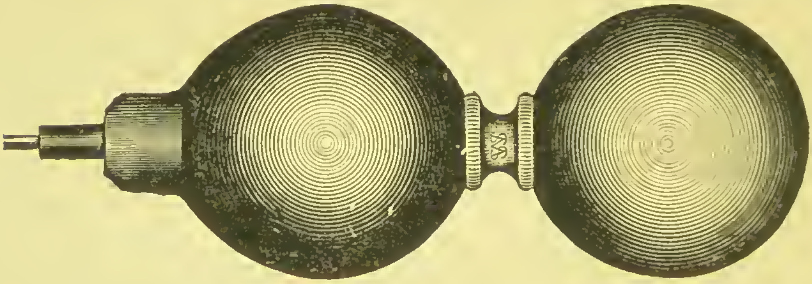

FIG. 177.—DUPLEX SYRINGE.

needs scarcely be noted that a tooth which requires bleaching is a pulpless tooth to begin with. Teeth having lost their pulps will exhibit a very high electrical resistance, due to the loss of connection between the tubular contents and the tissues surrounding the apex of the root. Then again the pulp canal may be filled with a non-conducting material so that the only path that the current can find will be in a lateral direction through the dentine and cementum of the root. It is obvious, therefore, that as previously pointed out, a large portion of the root filling should be removed prior to mak-

ing any attempt at forcing current through. At the beginning of the bleaching operation it may require as high as sixty volts to establish a path for the current. In the majority of cases, however, the requirements will seldom exceed thirty volts.

The amperage in bleaching cases will be a little more as a rule than upon sensitive dentine. The tissues at the apex of the root or those which surround the root are not of the highly organized structure that receives the first sting of the current in dentine anæsthesia. They are not so sensitive to the current, and the operator may therefore use more current in bleaching than would be tolerated upon dentine. Three to five milliamperes in this instance, would therefore be an average strength of current to be obtained.

The length of time consumed in bleaching will, like applications for sensitive dentine, depend upon the condition of the dentine and the area of exposure. The operator, in bleaching a tooth, can to a certain extent tell by the appearance of the tooth how long he can profitably continue the application. In bleaching, however, the many widely differing conditions that will be present, necessarily require a wide range of time. In favorable cases a tooth can be perfectly bleached in eight minutes and in others it may require forty-five minutes to obtain a satisfactory result.

It may be that cataphoresis has fallen into disuse in late years, but this is probably due to the great amount of care that is necessary in every step to make this operation a success. There is no operation in dentistry and especially upon dentine, in which there is required

of the operator such a broad knowledge of electricity and such an amount of painstaking care as a successful cataphoric administration. In the first days of this method pulps were killed by carrying the process too far, gum tissue was destroyed by leakage, severe shocks were produced by suddenly breaking the current, and these along with the amount of time consumed have contributed to the partial abandonment of cataphoresis. Experience has shown that, however much care may be necessary for a successful cataphoric application, in some cases it is the best agent at the dentist's command. Dr. Louis Jack says: "When the pain attending excavation requires active treatment, such as the employment of zinc chloride or general anæsthesia, the cataphoric method is far preferable to either, and is absolutely certain of giving relief. The results of successful cataphoresis are marvelous, and it may be truly stated that no advance of recent years in the therapeutic treatment of teeth is comparable to this."

CHAPTER XI.

The X-Ray.

The X-ray has no more fitting application than in dental practice. In medicine and surgery its use has never been questioned as an aid in locating foreign bodies, in diagnosing fractures and dislocations, in detecting the presence of calculi and pus cavities, and even the abnormalities of some of the softer tissues whose density differs but little from that with which they are surrounded. The X-ray is also of value in some of the arts and as the appliances are being perfected and new uses are found for it, its applications are still broadening. The most valuable field, however, will always be in medicine, surgery, and dentistry.

While the use of the X-ray in dentistry is not usually in cases in which it is a matter of life or death with the patient, as is frequently the case in surgery, its more frequent use, however, gives it a value of a high order. Its dental applications, while confined to a comparatively small portion of the body are of rather wide range and will require just as much skill on the part of the operator as in work upon the thicker tissues. For instance the dentist must be able to so manipulate his tube and appliance as to differentiate between the roots of the teeth and the bone which surrounds them, a feat equal to any accomplished by the physician. Or,

on the other hand, he may have simply the location of a broken broach or a pus cavity which are comparatively easy. The most frequent dental uses of the X-ray are for locating unerupted teeth, for ascertaining their position and the shape of their roots, for diagnosing fractures of the jaw, for locating foreign objects such as a broken broach, for determining the depth of root filling, the extent of an abscess, or the proportions of the antrum.

The successful use of the X-ray requires a somewhat formidable array of appliances, and the manipulation of them calls for one who is accustomed to mechanical details. To this extent the dentist is very well fitted at the very outset by the nature of his mechanical and digital acquirements. Instruments and instrumentation are his daily company and his occupation. Moreover, X-ray work being an electrical process, the majority of dentists are to a large extent familiar with the fundamental electrical requirements and are already equipped with many appliances which may be used in the work.

The discovery of the X-rays was made by Prof. William Conrad Roentgen of Wurzburg, Germany, in November, 1895. He was at the time professor of physics at the Royal University of Wurzburg. In 1879 Professor Crooks had made his classical experiments with tubes of a very high vacuum, and from that time till the discovery made by Roentgen, scientists were at work upon the phenomena of high vacuum tubes. Professor Hertz, of Bonn, in 1888, by means of a high-vacuum tube demonstrated the theory of light which had been propounded by Maxwell in 1864. The waves

discovered by Hertz have since borne his name. Professor Lenard, a former assistant of Professor Hertz, in 1894, made further experiments along the same line, and, in following up a suggestion thrown out by Hertz, found that the rays were transmitted to the outside of the generating tube. It was but a step further and a year later when Roentgen discovered still another ether wave which emanated from the tube. This differed from all other known waves, and for want of a better term, he modestly called them the X (unknown) rays by which they are commonly known to-day.

When an electrical connection has been made between two conductors the current will still flow across the gap if the conductors be slightly separated. Even as low as forty volts' pressure will maintain an arc half an inch in length provided the current has been once established by actual contact between the terminals. But to bridge a space in the ordinary atmosphere without actual contact is quite another problem. It is estimated that without previous contact it requires an electromotive force of about fifty thousand volts for every inch of air space bridged by an electric spark. It has been found, however, that if the air has been exhausted from a glass tube so as to leave about one-fifteenth of its original amount, an electrical presure which will jump only one-fourth of an inch in the open air, will pass through such a tube six inches in length. Tubes which have been exhausted to about three-thousandths of an atmosphere are regarded as of comparatively low vacuum and are known as Geissler tubes. They have been exhausted to a point where their electrical resistance is the least

and the electrical charges easily pass through them. As a matter of fact, an electrical discharge will take place through twelve feet of these tubes rather than jump a gap of three inches in the open air. In these tubes the current does not flow in the usual form of a spark, but in fluorescent coruscations. These effects can be made quite beautiful by using tubes of uranium glass, and by the introduction of various substances into the tubes, as a sulphate of quinine, iodine, the fluorides of boron and silicon, hydrogen and nitrogen.

If these tubes be now further exhausted, it will be found that the electrical resistance increases with the degree of exhaustion, and this may even be continued till a point is reached where it is impossible to force any current through it. The resistance of the tube becomes even higher than that of the atmosphere. If the exhaustion has been carried to about one-millionth of an atmosphere, it will require a pressure of one-half again as much electrical force to produce a discharge as that required in the atmosphere. Tubes of this character are known as Crookes tubes, and they also differ from the Geissler tubes in their form. Geissler tubes are usually long and of fantastic shapes, whereas the Crookes tube generally consists of an enlarged bulb with a stem which contains an inleading electrode and which also serves for holding the tube as shown in Fig. 178.

The vacuum of the Crookes tube is so nearly perfect that the tube has a very high resistance. In fact it borders so nearly on an absolute vacuum that the first tubes of this character employed in X-ray work became worthless in time because of a gradual rise of the vac-

FIG. 178.—CROOKES TUBE.

uum to a point where it became impossible to force current through them with even the most powerful electrical generators.

It is in such a tube that the X-ray is generated. The vacuum is so high that it requires the most powerful generators to energize the tube. As a matter of fact, the most efficient X-rays are generated in a tube which borders on an absolute vacuum. The nearer such a condition can be approached and the current still made to pass, the more penetrating will be the X-rays which emanate therefrom.

In the Geissler tube, which is of comparatively low vacuum, the molecules of the contained gases which ordinarily tend to move in straight lines are thrown into violent agitation because of the very short free path to which they are limited. As the vacuum is raised to that of a Crookes tube, the free path of each molecule is lengthened and the luminous effects disappear, only the glass containing wall appearing to have any color. This generally becomes a bright canary yellow when the tube is most efficient in the production of X-rays. The color appears to be in the glass itself, and while most tubes gives a yellow color, the German tube becomes a bright green and others have a bluish appearance.

While the nature of the X-ray has been a matter of speculation from the first, it is now generally conceded to be an ether wave of extremely high frequency. The different colors of the spectrum as they appear to the eye are due to different frequencies of transverse vibrations of the ether. They have a frequency of from about four hundred billions for the red to about seven hundred

and fifty billions for the violet. All the other colors are due to frequencies between these two extremes.

While the human vision is limited to a range of about three hundred and fifty billions, it would be unreasonable to suppose that there are no other vibrations of the ether. The actual spectrum has been demonstrated to be of much wider range, and that visible to the human eye is but the least part of it. Below the red end of the visible spectrum for a distance of fifty times the visible length are waves whose frequency is but a hundred millions. In this part of the spectrum, the infra red, are to be found the heat rays of twelve billions per second, the Hertz waves of two hundred and thirty millions per second, and still lower at only a million per second we enter the electro-statical radiations.

At the other extreme and beyond the violet end of the visible spectrum in the ultra violet, for ten times the length of the visible part are vibrations of increasing frequency. While these waves have no effect upon the human eye, they however, have actinic properties, and photochemical reactions take place in their presence. At the farthest extreme in this direction, and at a yet undetermined rate, are found the X-rays. Their rate of vibration is supposed to be at least trillions per second. Voller has estimated them at 288,224,000,000,000,000 complete vibrations per second. The discovery of the X-ray has added at least seven octaves beyond the known ultra-violet.

The precise nature of an X-ray wave is still unknown, but most scientists lean to the belief that it is a transverse vibration of the ether. Roent-

gen at the time of the discovery was of the opinion that it was a longitudinal vibration, for he says: "It has long been known that besides the transverse light vibrations, longitudinal vibrations might take place in the ether, and according to the view of the different physicists, must take place. Certainly their existence has not up till now been made evident, and their properties have not on that account been experimentally investigated. May not the new rays be due to longitudinal vibrations in the ether?"

His second paper did not, however, touch upon the nature of the X-rays which indicates that he was not yet satisfied in his own mind as to their exact nature, and the most recent investigations show them to be transverse vibrations of the ether, but of an extremely high frequency and of proportionately short wave length.

The X-rays differ from other known ether waves in certain particulars, which entitle them to a distinct classification. Light rays may be refracted, deflected, or condensed, but the X-rays cannot be made to do so. They can, however, to a small extent, be diffused. The Lenard ray which also emanates from the cathode very closely resembles the X-ray, but this ray can be deflected by a magnet which indicates that it is of a different nature. Moreover, the Lenard ray can be generated in a vacuum of one ten-thousandth of an atmosphere, whereas the X-ray vacuum must be much higher than that. The X-rays pass out from the tube in straight lines and only suffer as to their intensity which is inversely proportionate to the distance from the tube.

The energizing of the X-ray tube requires a current of exceedingly high pressure and of comparatively small ampere strength. This can, at present, be produced by three appliances: the static machine, the induction coil, and the Tesla coil.

The static machines are of several varieties, but those named after Holtz and Wimshurst have proven themselves most efficient and reliable. The Holtz machine consists of two or more glass plates, one of them fixed and the other so mounted that it is free to revolve. The stationary plate has two circular openings called *windows,* which are in a position opposite two metallic combs on the front side of the movable plate. On the rear surface of the stationary plate are two paper *inductors* extending one-sixth of the distance from one window around toward the other window. The edge of the paper at the window opening is armed with a row of points which project into the window. The Holtz machine is sometimes made up of a number of plates which increase the strength of the discharge which for X-ray work is quite essential. In some machines of this type, as many as twenty-four plates are assembled on one shaft. The plates of such machines need not necessarily be made of glass, but may be made of hard rubber or mica.

The principal modification of the Holtz machine was made in 1883, by Töpler, who fastened a number of small foil discs with raised centres on the movable plate. Four very light wire brushes are also employed, two being attached to the stationary plate and two to the combs in front which touch lightly on the raised discs as

they pass. The metallic discs always carry a feeble electrical charge and in this way the machine becomes self-exciting or self-charging. A few years later Atkinson made some improvements in the minor details and the machine now bears his name.

This machine is very susceptible to moisture and dust and on that account is generally enclosed in a case as shown in Fig. 179.

The moisture within the case may be taken up by any dehydrating agent. Chloride of calcium is generally used for this purpose, a vessel of the same being placed in the enclosure. It is also important to keep the room at a temperature as uniform as possible.

The other form of static machine frequently employed is the Wimshurst invented in 1883. This consists of one of more pairs of glass or vulcanite plates, which are made to revolve in opposite directions, thus doubling the speed at which the plates pass one another without endangering the plates. Metallic carrier strips are cemented radially upon each plate.

A curved metal rod is placed in front of each plate at an angle of ninety degrees from the one in front of the next plate. The ends of the rods are fringed with a delicate metallic brush which plays upon the carrier strips as they pass. At a point forty-five degrees between the curved rods is fixed a set of combs which enclose diametrically opposite edges of the plates.

When the plates are set in motion they receive an initial charge by the friction of the brushes. Since they revolve towards one another the charge is increased by induction, and in this manner heavy discharges soon

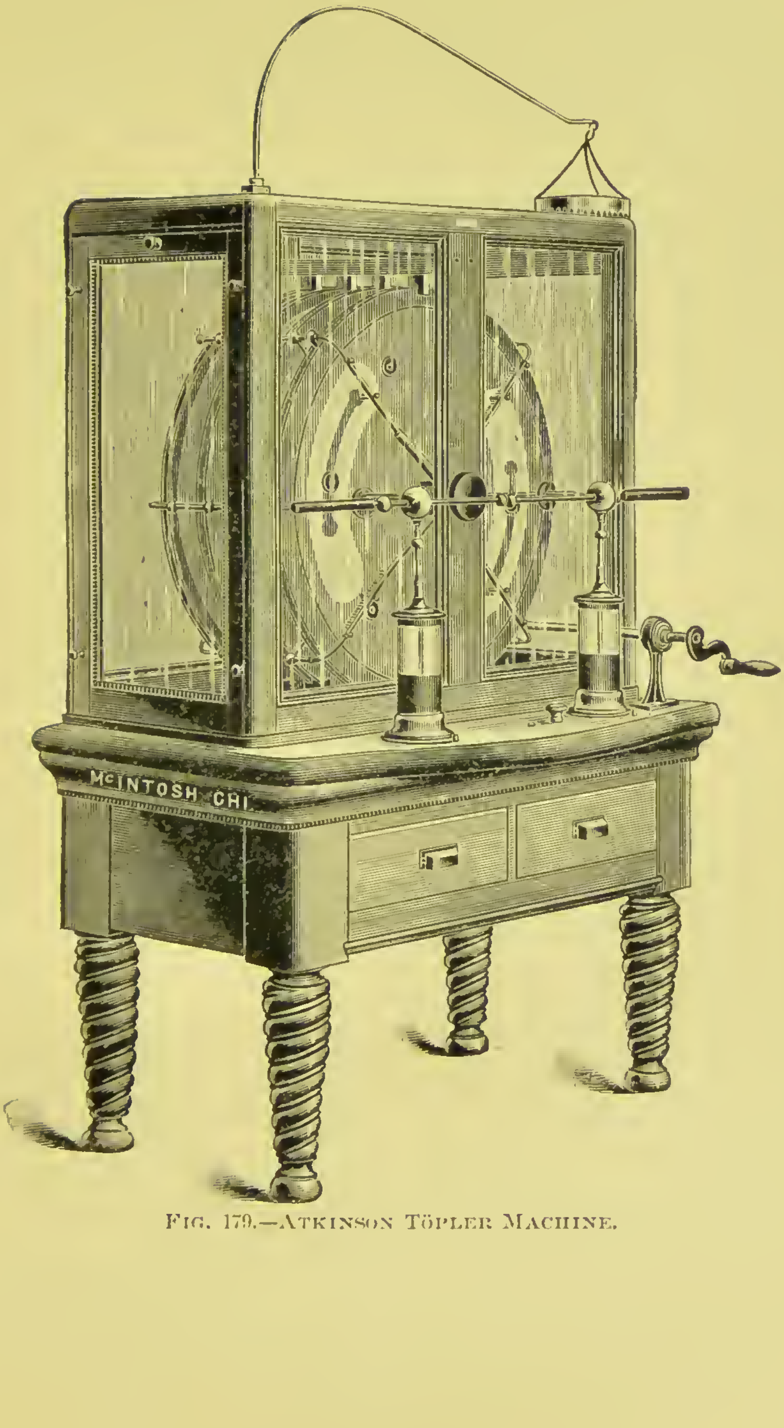

FIG. 179.—ATKINSON TÖPLER MACHINE.

take place between the knobs which are in connection with the collecting combs.

The Wimshurst machine does not suffer an automatic reversal of potential, as sometimes occurs with the Holtz and Töpler machines even while they are in operation.

The second method of generating current for the X-ray tube is by means of the induction coil. This is sometimes called from its inventor, the Rhumkorff coil. The underlying principle is that of induction discovered by Faraday in 1832. If a current of electricity be caused to flow in a conductor in impulses, or better still in complete breaks, the ether surrounding the conductor will convey a magnetic impulse to a wire parallel with. but entirely insulated from the first conductor. This magnetic impulse causes a current of electricity to flow in the second wire, but in a direction opposite to the impulses in the first wire. The potential of the second impulse or secondary current is proportionate to the first, if the same length of wire is employed in each coil. It was soon found that by increasing the length and the number of turns of the secondary coil, the potential of the secondary would be increased. Or, if the proportion be reversed, and the primary current be sent through the fine wire a current of low potential but of high ampere strength will flow in the coarse or short wire. This principle of the Rhumkorff coil is commercially employed in the transformer used for the reduction of a high-volt current to one of low pressure. It should be borne in mind, however, that as the voltage of one coil is raised by increasing the number of turns, the ampere strength of the current proportionately de-

creases. In X-ray work a current of very high voltage and very little ampere strength is necessary, and for this reason the induction coil should have a very large secondary as compared with its primary. In the practical construction of a coil which will give a secondary spark

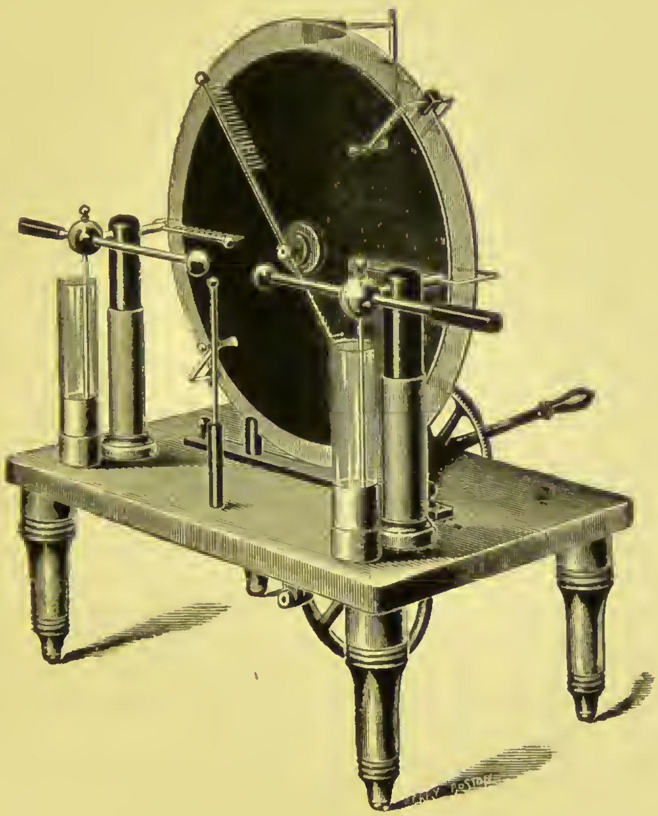

FIG. 180.—WIMSHURST MACHINE.

of ten inches, the primary coil is made up of two or three layers only of twelve or fourteen gauge copper wire, while the secondary coil requires about ten miles of thirty-six gauge copper wire. The great Apps coil which gave a forty-two inch spark contained two hundred and eighty-six miles in the secondary.

The induction coil to be most efficient, however, should

have its primary coil wound upon a soft iron core the effect of which is to increase its induction. The core is best made by using a bundle of the softest iron wires of about eighteen or twenty gauge. The object in having it in this fine state of division is that it may take up and lose its magnetism more quickly, and also to prevent undue heating and Foucault currents. In the manufacture of the best cores the wires are frequently shellaced, or perhaps the whole core when assembled is immersed in melted paraffine. When the core is completed it is wound with a layer of insulating tape.

The primary coil generally consists of from but two to four layers of about No. 12 to 14 gauge insulated copper wire. This winding is made upon the core just described, from end to end. In the best coils it is customary to make the core and the primary winding somewhat longer than the secondary, and, by so doing, if the secondary is placed over the middle of the primary, it is in the most intense inductive field. The insulation of the primary should be good, for while there is not a great difference in potential between the different turns, the short-circuiting of the different layers would be a serious matter. The greatest precaution, however, should be observed in insulating the primary from the secondary. This can only be done by the use of a very thick hard rubber tube. In the larger coils the walls of this tube are sometimes an inch in thickness and cover the full length of the primary coil.

The most important part of the induction coil lies in the winding and insulation of the secondary coil.

There must be not only perfect insulation between the successive turns of wire, but the greatest precaution is necessary to have sufficient insulation between the secondary and the primary. For instance, a coil which is capable of giving a fifteen-inch spark between its terminals, must have an insulation between it and the primary coil which it surrounds, capable of withstanding a pressure of about seven hundred and fifty thousand volts. On the other hand, the nearer the secondary is wound to the primary the more efficient will be the coil. For this reason the rubber tube which separates the two must be of the most perfect construction in order that it may be as thin as possible and at the same time be able to withstand this enormous pressure. It is much easier for the secondary current, were it not for the insulation, to jump to the primary coil and core than to bridge the full space between the terminals upon the outside of the coil. It is not impossible, however, by sufficient care, as has been demonstrated, to make a coil with such good insulation that the spark will be even longer than the secondary coil itself. The author's own Queen coil has a secondary coil of but thirteen inches in length and yet it is capable of giving a full fifteen-inch spark.

The wire with which the secondary is wound is usually a thirty-six to forty gauge, according to the size of the coil and the purpose for which it is to be used. As a rule, the larger the coil, the larger the wire. In the great Apps coil, No. 34 was employed for the larger part and at the ends the size increased to twenty-eight gauge.

The winding of the secondary in small coils is a very simple matter, being much like thread is wound

upon a spool; but if such a method were carried out in a large coil, the tendency of the current to jump from layer to layer in spite of the most perfect insulation would be too great, and such a coil would short-circuit itself very quickly. The method pursued in the winding of the secondary of large coils is not to arrange the layers horizontally with the core, but perpendicularly thereto. This is accomplished by winding the secondary wire in a disc-like form, and assembling these discs side by side upon the tube which insulates the primary from the secondary. A form is made with a hub the size of the outside diameter of the insulating tube. The sides are two removable discs whose outside diameters are as large as, or perhaps larger than the secondary coil is to be, and are about one-eighth of an inch apart. This form is then mounted in such a manner that it may be revolved. The secondary wire in passing from its spool to the form is caused to pass through a vessel of melted paraffine. The paraffine not only assists in the insulation, but when the form is filled and the paraffine has cooled, the sides may be removed and the discs may be handled without danger of displacing the wires.

When the proper number of these discs of coiled wire has been made, it being customary to make the secondary about twice the length of its diameter, they are assembled upon the ebonite tube, a disc of thin vulcanite, or of heavy paraffined paper separating each of the coils. The coils are put on in such an order that in connecting them together the ends of neighboring coils always meet either at the center or at the circum-

ference, observing at the same time that the wire continues in the same direction around the core. In the larger coils the discs which are at the ends sometimes have a larger center than those in the middle so as to reduce the danger of sparking through to the primary.

When the secondary is assembled and the connections between the discs have been soldered the entire coil is

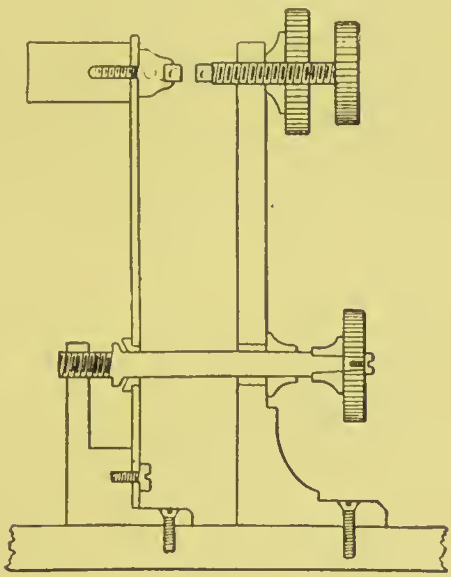

FIG. 181.—THE INDUCTION COIL VIBRATOR.

immersed in melted paraffine till all the air has been driven out, thus insuring a still higher degree of insulation. The coil is then ready for the mounting.

The next step and a very important one is the construction of the vibrator or wheel whereby the current is to be interrupted. The vibrator as shown in Fig. 181, consists of a weighted spring which is drawn towards the core upon the latter's being magnetized by the current. Just as the spring has about reached

its full swing toward the core it breaks the electrical connection at C for the primary coil, and in so doing is magnetically released. Upon swinging back the electrical connection is again made, when it is again drawn toward the core and the current again broken. In this manner the current is automatically made and broken by the swing of the vibrator. The strength of magnetic induction depends upon the length of time

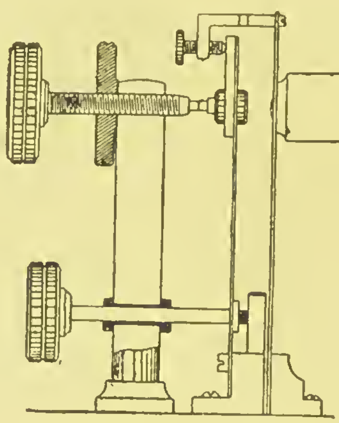

FIG. 182.

that contact is made, the abruptness of the break, and the rapidity of these changes per second. The first vibrators consisted simply of a weighted spring so constructed that the rate of vibration could be varied either by moving the weight up or down, or by varying the tension of the spring by means of a screw as shown in Fig. 181.

The more modern and efficient vibrators are so constructed that, by means of a double spring as shown in Fig. 182, the contact is not broken till the weighted spring is at its fastest speed. The contact has thus

a comparatively long period of time and a very abrupt break.

The second method of interrupting the current is by the use of a recently devised appliance known from its inventor, Dr. Wehnelt, as the Wehnelt interrupter. It is also known as the *electrolytic* interrupter by reason of the phenomena upon which it is based. This appeared early in 1899. It consists of a glass vessel about the size of an ordinary battery jar in which a lead plate forms one electrode and a platinum point forms the other. The electrolyte is a dilute solution of sulphuric acid of about the same proportions used in the storage cell, or, one of acid to four of water. The platinum electrode was first made by sealing a piece of 24-gauge platinum wire in a glass tube allowing about one-eighth of an inch to project therefrom. This was found to be very easily broken by reason of the heat and the violent action about the point. To overcome this objection, Dr. W. A. Price has suggested the use of a clay pipe stem with a platinum wire which neatly fits the hole and especially at the opening. The wire being movable, can be easily adjusted so as to present either a large or small point.

It is important in making the connections to see that the positive wire is connected to the platinum electrode and the negative wire to the lead electrode, otherwise the platinum point would be quickly melted.

The theory as to the manner in which this form of interrupter acts when used with induction coils is this: The wire, as the result of electrolysis becomes enveloped in a gas. This acts as a very high resistance for the

moment and an explosion follows which effects a complete break in the current. These explosions are due to the ignition of the gases by the spark which follows the first breaking of the current. They take place with great rapidity, varying from two hundred to two thousand per second. Their frequency varies directly as the voltage and inversely with the exposure of platinum.

The virtue of the Wehnelt interrupter lies in the abruptness of the break and in the frequency of the same. No mechanical appliance has yet been devised which can produce an interruption of an equally clean cut and which at the same time produces the rapidity of interruptions.

When induction coils are operated by mechanical interrupters it is necessary to employ a condenser. This lessens the spark at the place of interruption and increases the inductance of the primary by discharging into it when the circuit is again closed. When the electrolytic interrupter is used, however, the condenser is dispensed with.

A peculiar feature of the Wehnelt interrupter, however, is that it is not so well adapted for use with large coils as with small ones. Its efficiency is best when used upon coils which give a spark not exceeding ten inches. This is accounted for by supposing that the frequency of interruption is so high that the current in the large coils does not reach its maximum before it is interrupted. When used upon coils not exceeding ten inches their efficiency is almost doubled; whereas coils which give only a thin spark of a given length when operated by a vibrator, not only give a thicker spark

but a much longer one. Another peculiarity of this interrupter is a tendency to suddenly stop its operations when too much current is sent through it. A yellowish glow is seen around the platinum point and if the insulating tube is of glass it appears much as if the current were trying to enlarge the surface of the platinum point by breaking through the glass sheath.

There are two objections to this interrupter. One is the noise which accompanies the interruptions and the other is the fumes that arise from the electrolytic action. The noise, however, is not more than usually accompanies the operation of an induction coil by other methods, and the fumes may be taken care of by covering the cell with a close-fitting lid.

While the vibrator or the Wehnelt interrupter is all that is required for smaller coils, those giving over a ten-inch spark, on account of the heavy current necessary, require a different method of breaking the current. Beyond a certain current the platinum contacts become heated, and frequently weld together so that a more certain method is necessary. This brings us to the third method of breaking the current which is by means of a wheel appliance. This is furnished with the Edison coils as illustrated in Fig. 183. The advantage of the wheel over the vibrator when used on large coils and with a necessarily heavy current is that the break of the current is absolutely insured. Whenever the primary current of an induction coil is broken there is always a large spark, much larger than when a current of like strength is ordinarily broken. This is because of the iron core and induction. Moreover, by the

use of the wheel, the length of contact can be proportioned to be the most efficient in a very simple and easy manner, and the abruptness of the break can be secured by means of a blast of air directed upon the spark. The rate of breaking the current can be controlled by the usual rheostat regulation of the motor. The wheel appliance for doing this work consists of a brass casting with outwardly projecting lugs which make contact as

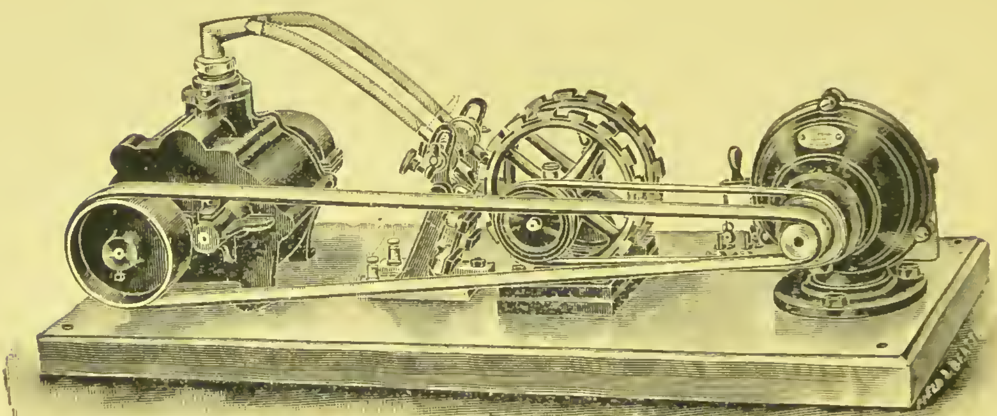

FIG. 183.—EDISON WHEEL APPLIANCE.

they pass under a brush. The length of contact depends upon the breadth of the lugs in proportion to their distance apart, the distance between them representing the proportionate time of the break. In the appliance illustrated the proportion of contact to break is about two to one. It will also be noticed that there are two wheels which operate in parallel. By this arrangement the current is broken in two places at once which reduces the spark one-half at each brush.

Based upon the above theory of induction the author made for his fifteen-inch Queen coil which is shown in

Fig. 184, a mechanical-break appliance. This consisted of four slate wheels one and one-half inches by four inches in diameter mounted upon a shaft. Each wheel has six brass segments inlaid in the periphery so as to be smoothly flush with the slate. Four pairs of brushes bear upon the slate wheels. The brushes are half an inch wide and half an inch apart. These are

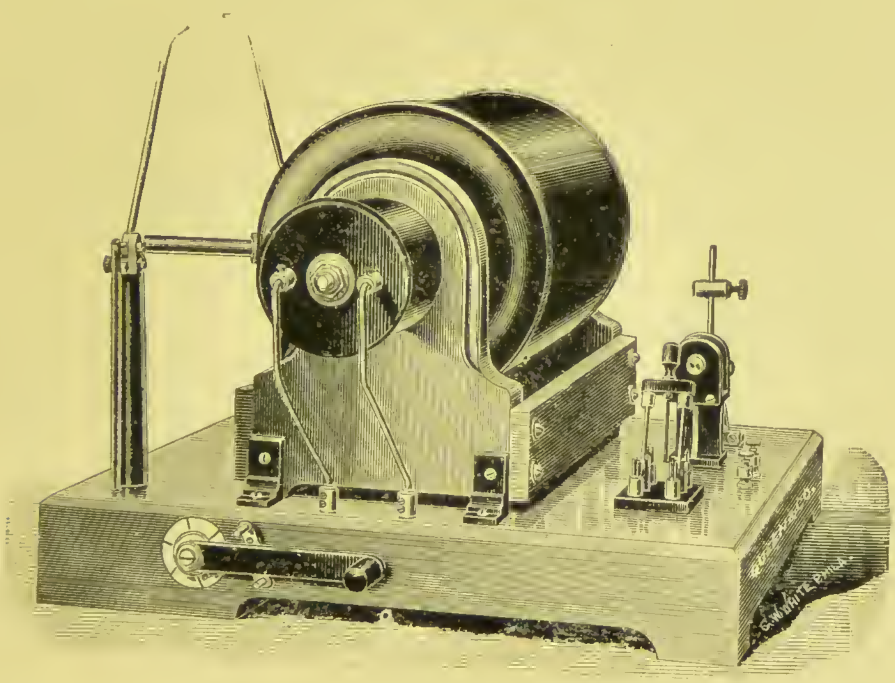

Fig. 184.—Fifteen-I ch Queen Induction Coil.

connected together in pairs so that when the cylinder is revolved, if they bear upon the plates complete connection is made throughout and if they bear upon the slate the current is likewise broken throughout. They are so accurately adjusted that as the cylinder is revolved the four segments slide from under the brushes at precisely the same instant. In this manner the

circuit is broken at eight places simultaneously, the effect of which is the same as if the wheel were revolving at twelve times its speed. It thus decreases the length of the spark at each brush to only one-eighth what it would be if one brush were used. The reduced spark thus allows the metallic segments to be made very wide in proportion to the insulating separations of slate. In practice it is desirable to have only enough distance between the contacts to insure complete extinction of the spark. If the spark were to bridge

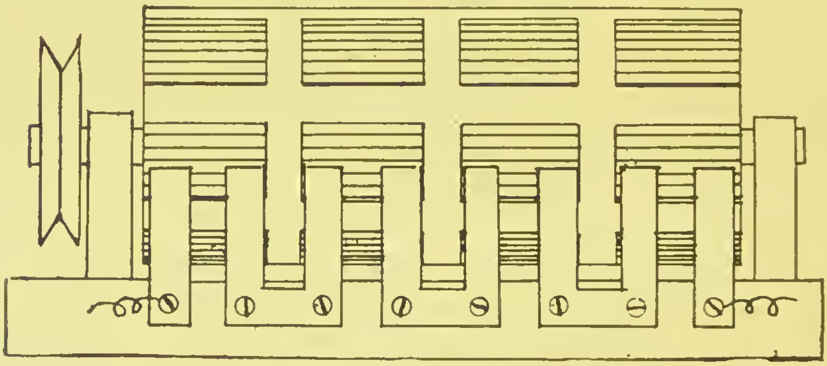

FIG. 185.—AUTHOR'S BREAK APPLIANCE.

from segment to segment, the inductive effect would be destroyed. In short, the eight simultaneous breaks in the current allow of very long periods of contact in proportion to the periods of break, and thus permit of a higher speed, the effect of both of which is to increase the inductive effect a great many times. This result has been very marked in the author's coil. Where the vibrator as supplied with the coil gave only a thin spark even when the points were quite close together, the wheel appliance gave a flame between four and five inches in length, and when the spark gap was at ten inches a stream of

sparks passed which the vibrator could only equal when the gap was but one to two inches wide. The difference of effect was even more marked in the tube; whereas the vibrator at all times produced a flickering light in the fluoroscope, the cylinder gave a steady fluorescence equal to that given by the static machine, the chief point of merit of the static machine for X-ray work. Moreover and more important, the X-rays emitted were of such volume and their effect of that clearness that exposures were made in half the former time, and the sciagraphs had a clearness of detail that was never seen before.

An induction coil is not complete nor can it be at any time so highly efficient without the use of a condenser around the break. This great improvement was made by Fizeau. In the older forms the Leyden jar performed the function of the condenser, but a Leyden jar for this purpose, to have any considerable capacity would require a large amount of room space. It became the custom to make the appliance by building up alternately sheets of tinfoil and paraffined paper till a pile of sufficient capacity had been obtained. It was then known as the condenser and occupied a small amount of space.

The condenser is constructed by using a large number of sheets of tinfoil which are insulated from one another by some dielectric such as paraffined paper or mica. Theoretically the thinner the dielectric, its insulative property being certain, the more efficient will the condenser be. The author prefers the mica in thin sheets such as are used for stove windows for this purpose, for

the reason that it is a good dielectric and is not so thick as the paraffined paper. The condenser is built up in the following manner: The mica sheets should be about three and a half by four inches and for a condenser of sufficient capacity for a twelve-inch coil about ten pounds will be necessary. The tinfoil can be cheaply obtained of a florist and this is cut into sheets two and three-fourths by four inches. A sheet of mica is shellaced on one side and a sheet of the foil is placed upon it in such a position that there will be a margin of three-eighths of an inch at all the edges but one. At this one it will extend three-eighths of an inch beyond. When all the mica pieces have been covered in this manner they are to be assembled. The first layer of mica and tin foil is shellaced and the second piece of mica and tin foil is carefully placed upon it but with the projecting end of foil opposite that of the first layer. This is shellaced and the third piece of mica and foil is then placed in position with its free end of foil in the same direction as that of number one. When about a hundred of these have been properly assembled the even numbers of foil will all appear at one end of the pile and the odd numbers at the other. The pile is then of convenient size for handling and is put under a weight and the foil at each end melted into a mass by means of a soldering iron. Wires are then attached to the two ends, and after the shellac is dry this section is complete.

In like manner the rest of the mica and foil is assembled and when all are complete the wires of one side are connected to one binding post and those of the other

side to another binding post, when the condenser is complete. Such a condenser will have a capacity sufficient for the largest coil for X-ray work.

The condenser serves as a reservoir for the extra induced current in the primary coils by virtue of the iron core, and also for the back inductive effect of the secondary coil. The effect of these influences is to create a heavy impulse in the primary coil in the opposite

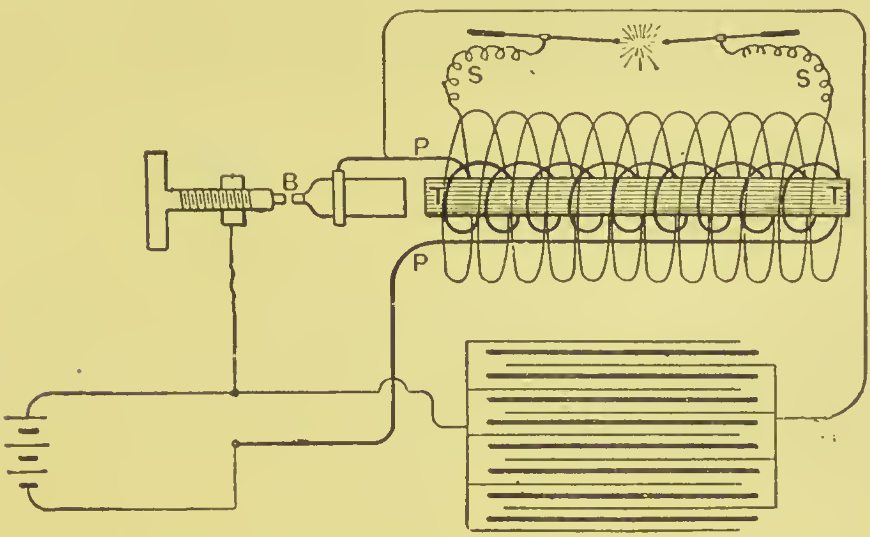

FIG. 186.—DIAGRAM OF INDUCTION COIL AND CONDENSER.

direction, the moment the current is broken by the vibrator. This lessens the strength of the primary current when it begins to flow again, and the two opposing forces waste their energy in the useless and destructive sparking at the contacts. When the condenser is employed its terminals are attached one on each side of the spark gap as illustrated in Fig. 186, the effect of which as previously stated is to form a store or reservoir for the momentary congestion. The extra current

rushes into the condenser charging it just as a Leyden jar is ordinarily charged, and when connection is made again it discharges itself in the same direction in which the current is going, thus augmenting the strength of the primary current as well as reducing the spark at the contacts.

The General Electric Company supplies an X-ray

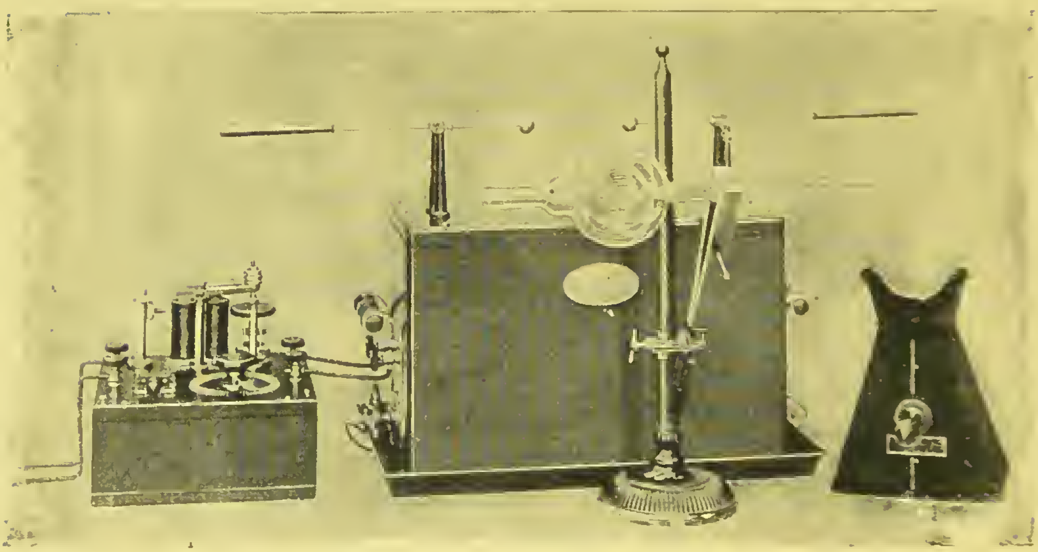

FIG. 187.—GENERAL ELECTRIC COMPANY'S COIL.

outfit of the induction coil class in which the coil is immersed in oil for insulation. This is shown in Fig. 187. The condenser and circuit breaker are separately mounted. The condenser is enclosed in a box on the top of which the circuit breaker is placed. The circuit breaker is unique in that the circuit is broken under water which insures quick and complete elimination of the spark.

The third method employed for the generation of current for X-ray work is the Tesla coil. This takes its

name from its inventor who has made such brilliant experiments with high frequency currents. This apparatus produces a current of a very high potential and high frequency. It consists practically of two induction coils so connected that the secondary of the first acts as the primary of the second coil. This is diagrammatically shown in Fig. 188. The first primary P, of the best proportioned of these coils and the

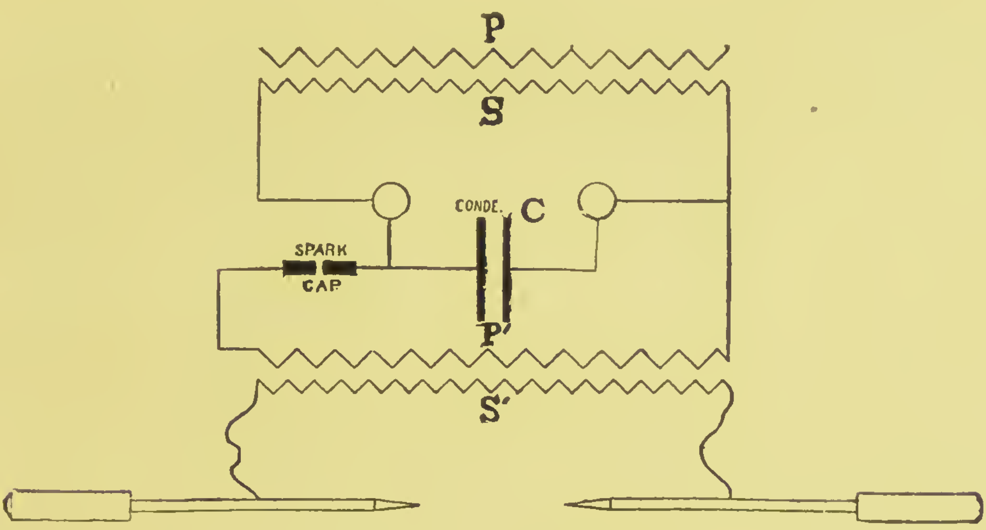

FIG. 188.—TESLA TRANSFORMER.

first secondary S, are not of such wide difference in the comparative number of turns as in ordinary induction coils. They are usually of the proportion of one of the primary to twenty-four of the secondary. The first secondary terminals are connected on one side to the condenser C, and the second primary P′, and on the other side to the other terminal of the condenser and also to a spark gap. The second secondary S′ terminals lead out to the discharge points.

In order to secure the most perfect insulation the two coils and the condenser are generally encased in a box which is filled with boiled linseed oil. Such an outfit is shown in Fig. 189.

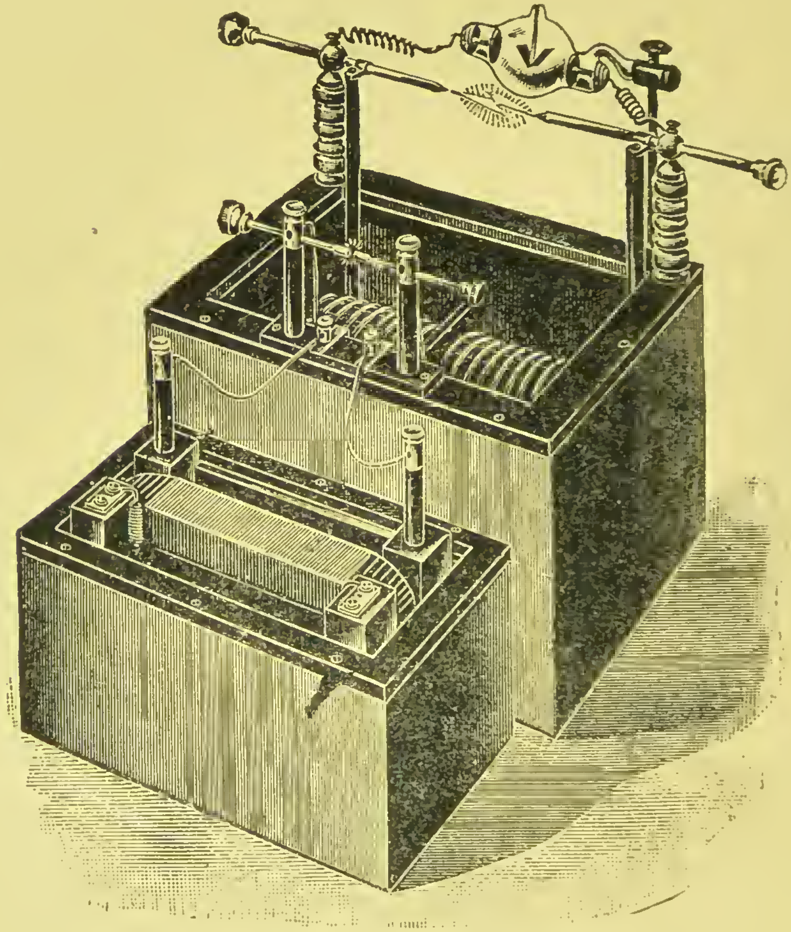

FIG. 189.—TESLA TRANSFORMER IN CASE.

In the practical operation of these coils, the primary current is best obtained from the alternating current as commercially supplied. The first primary is wound for fifty-two or one hundred and four volts, so that no extra

resistance is necessary; and if the manufacturer has been thoughtful he will have made a connection in the middle of the primary coil, so that by connecting thereto with one terminal and at both ends with the other terminal, the halves of the primary coils will thus be in parallel and will operate on fifty-two volts. Or if the connection be made to the end terminals only, the coil

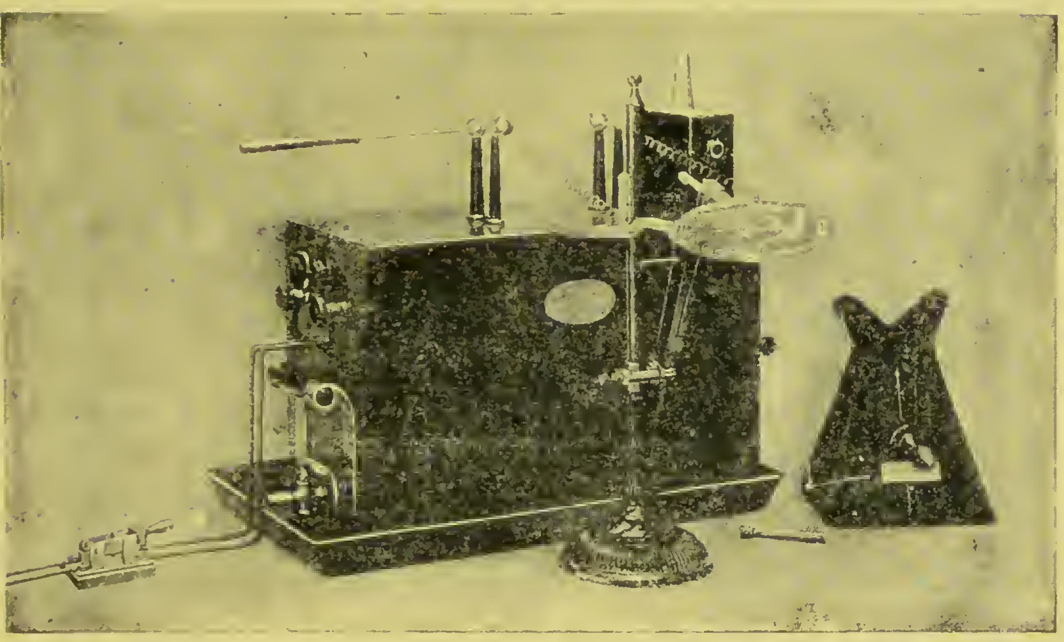

FIG. 190.—THOMSON TRANSFORMER.

will have the proper resistance for one hundred and four volts.

Perhaps the most important part of the Tesla appliance is the condenser. The function of the first induction coil or transformer as it is sometimes called, is to charge the condenser. When the condenser is charged sufficiently to leap the spark gap a current passes through the second primary. The peculiarity of these

discharges is their very high frequency which is the essential part of this process of electrical transformation. Added to this is the increased voltage by virtue of the multiplying effect of the second secondary coil. We thus get a current of exceedingly high frequency of oscillation and of high voltage.

The efficiency of the Tesla transformer depends largely upon the sharpness of the break of the first secondary current at the spark-gap. If this were a drawn-out arc the condenser would not charge. If, however, a wheel with about fifty outstanding teeth upon its periphery be revolved at a very rapid speed past a knob, these discharges will take place very rapidly and will be of the necessary sharpness.

The General Electric Company manufactures a coil much like the instrument just described. This as shown in Fig. 190 is all contained in a single case. The coils are immersed in oil and the whole set within a tray.

The relative advantage of the three methods of exciting the X-ray tube may be summed up as follows:

The static machine gives, in general, a clearer definition of the object in the fluoroscope, and sciagraphs made by it are said to be the most distinct. This is due to the uni-direction of the current. The static machine is also less liable to produce a burn, but in the present light on this subject such a thing with any appliance would be due to carelessness in exposures of less than ten minutes duration.

The objections to the static machine are mainly its unreliability and bulk. The static machine is easily

affected by the temperature and the humidity of the atmosphere. Some forms of the machine are liable to reverse their polarity, and this sometimes occurs during the use of the tube. It cannot for these reasons be relied upon to give the same results in each case, the subject and the length of exposure being the same.

The Rhumkorff coil has features of advantage which recommend it especially for the dentist's use. Its absolute reliability and its uniform behavior are the chief points of advantage. It is not affected by climatic changes, its output can be regulated and controlled to the finest degree, and it requires the least amount of room space for its accommodation. These are features of considerable importance. Moreover, heavy currents for certain kinds of work can be best obtained from this coil.

The objections to the Rhumkorff coil are principally that the definition is not quite so clear as with the static machine, and that it is liable to burn the patient. If, however, a wheel is employed for interrupting the current as employed by the author and previously described, the definition will be equal to the best static machine; and the burns may be avoided by the simple placing of a foil-coated sheet of paper between the tube and the patient with the foil coating grounded by a fine wire connected to the nearest gas or water pipe.

The Tesla coil is the least valuable and the least certain of all for practical use unless used on the alternating current. Any attempt to use it upon the constant current will be more or less a failure. When properly used this instrument is capable of producing very bril-

liant electrical effects and most powerful currents for X-ray work, but the erratic behavior of both the coil and tubes are serious objections to this form of appliance. Moreover, the puncturing of the tubes so frequent with the use of this coil is a great objection. It was not till some half dozen tubes had been ruined by the author that he was able to manage them properly, and even now the full power of this coil is never employed for fear of puncturing a tube. Dr. C. E. Kells has recommended the grounding of a wire brought in close proximity to one end of the tube as a prevention of puncture, but as this acts by diverting energy from the tube it is to that extent a serious loss. Another objection to the Tesla coil is the necessary amount of noise during its operation; the sparking of some forms of the appliance is sufficient to frighten the bravest patient.

All things considered and at the present state of perfection of X-ray appliances, the dentist will obtain the most satisfactory results from a Rhumkorff coil. It is also recommended that he get one large enough for general work. The city dentist who is in touch with the general physician or with some established X-ray laboratory will be most practically profited by the use of an eight or ten inch coil, but if he expects to derive the most pleasure and benefit from the work he should get a twelve or fifteen inch coil, for then he will be able to manage all parts of the body. For the country dentist the larger coil is especially recommended, for the reason that the electrical part of his dental office appliances will already form a large part of his equipment and many

physicians will prefer to avail themselves of its use rather than to take up the work themselves.

It is customary in taking a radiograph, as the X-ray picture is sometimes called, to use a plate for large subjects and a film for the smaller. For dental operations the film has especial advantages: it is cheap, convenient to handle, easy to prepare, and is flexible. A cartridge of one and one-half inch film such as is used in the "Brownie" camera will be found to be the most economical, and this can be had at all photographic supply houses. The width of this film is the most convenient; the average dental case can be taken upon a square cut from the end, and if the case calls for a larger piece, it is only necessary to cut off an oblong piece sufficient for the case and place the strip lengthwise.

The plates to be used for larger subjects may be found upon the market. When necessary, ordinary photographic plates may be used for X-ray work with splendid results, but plates especially prepared for X-ray pictures such as the Cramer or the Carbutt are recommended. These plates are supplied either in, or with, light-proof envelopes. The author has found the Cramer Crown brand of plates to give results almost as good as the specially prepared plate for X-ray work. Plates which are prepared particularly for X-ray purposes usually have two or more coatings. The finest details in X-ray pictures are obtained by the use of multi-coated plates. These take longer to develop and fix but in so doing the operator is repaid by the better results.

The next step is the providing of a light-proof and to

a certain extent moisture-proof covering for the film. If the dentist has a good coil and becomes expert in the management of his appliance, he will require but a few seconds for an exposure and his film may be enclosed in two thicknesses of black paper without danger of light or moisture. The film is placed sensitive side down upon a piece of paper three by four inches and the edges all turned over upon the back of the film. This is then placed upon another piece of the paper somewhat larger than the first and enclosed in the same manner. A little gummed paper will prevent the flaps from opening. The film thus enclosed is flexible and neat, and can be easily adapted to any part of the mouth.

If the dentist requires a considerable length of time for an exposure, he may enclose his film in black unvulcanized rubber as suggested by Doctors Van Woert and Price. The film should first be covered with an envelope of tissue paper to prevent adhesion of the rubber to the film and also any injurious effects of the rubber upon the film. The black rubber being quite flexible and adhesive, a piece is cut twice as large as the film. The film is placed upon one half and the other half is turned over upon it and the edges pinched together. This makes a light and moisture-proof covering, and a film protected in this manner may be immersed in the saliva without danger of injury therefrom.

Dr. C. E. Kells has suggested the use of a little plate holder. This is made by first taking a modelling compound impression of the coronal and lingual aspect of the teeth to be skiagraphed. A piece of twenty-eight

gauge aluminum is attached to the inner side of the compound, and to this the piece of film protected as previously described is attached by little clips. The whole is then placed upon the teeth and the patient instructed to close the mouth. There are two advantages in this method: It leaves the operator free to manipulate the instrument and the film can be held more quietly. This method is especially valuable where, by the nature of things, from thirty to ninety seconds are required for a dental skiagraph, but when a large and efficient coil and tube are employed and but from three to ten seconds are necessary the film can be held quiet for that length of time by the assistant.

The film having been prepared, the patient is comfortably seated in an ordinary chair with a portable head-rest upon the back. An ordinary chair will be found most convenient for the reason that in taking skiagraphs of the upper jaw it is necessary to place the tube well above the patient to have the rays strike the plate perpendicularly and to get the teeth with the least distortion. For the lower teeth it is only necessary to rest the head well back in the head-rest. In making these adjustments the aim should be to seat the patient in such a position that the film when in place will face the tube so that the rays will be received perpendicularly thereon. It should be borne in mind that clearness of definition and correct proportions are lost if the plate is not at right angles with the tube.

While there is very little danger of producing a burn upon a patient in taking a dental radiograph owing to the shortness of exposure, the tube should nevertheless

be placed at least twelve inches from the surface of the face. Although the time of the exposure is lengthened by increasing the distance between the tube and the film, even fifteen inches would not be too far, and with an efficient instrument it should never be less than that. It should be borne in mind that the rays emanate from a very small surface and proceed outward in straight but diverging lines, and the farther the object is stationed from the target as the point of emanation is sometimes called, the more nearly parallel will the rays be. Every radiograph is larger than the original, but this disparity becomes less by placing the object at a distance from the tube. Nor are these the only advantages to be derived from operating at a distance from the tube. The patient, always a little timid at first, feels more secure at a greater distance and the operator has more room for manipulation. While a greater distance requires more time, the dental operations naturally require so little that this may be doubled and yet not be too long. The increase of distance is also compensated for in another way; while it may take a longer time, any movement of the patient is not so largely magnified as it would be if the distance were less. It may be roughly stated that the time required is proportionate to the square of the distance from the tube. The author has found that in practice the dentist may estimate the length of time in the following manner: If by experiment he finds that with a certain condition of tube it requires fifteen seconds at twelve inches from the tube, he will find that to get the same result twenty-four inches from

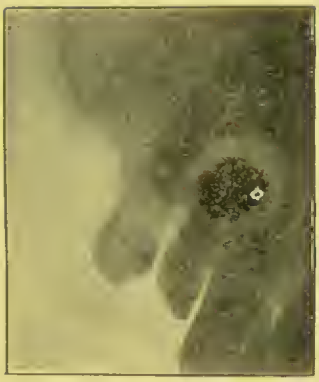

FIG. 191.—ODONTOME AND ABSCESS.

FIG. 192.—TEMPORARY AND PERMANENT INCISORS IN SITU.

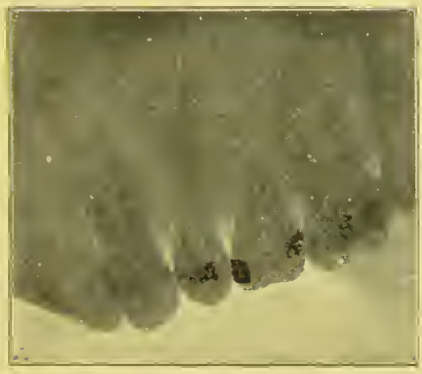

FIG. 193.—ABSENCE OF SECOND BICUSPID AND RETAINED TEMPORARY MOLAR.

FIG. 194.—BROACH EXTENDING THROUGH ROOT OF CUSPID INTO THE NASAL CAVITY.

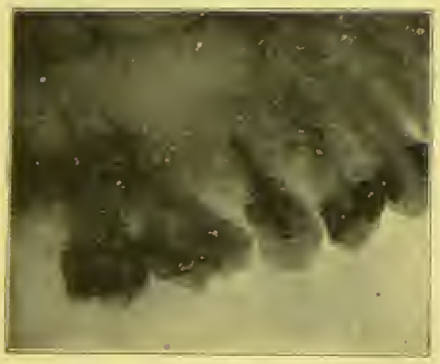

FIG. 195.—SHOWING MOVEMENT OF THE TEETH FOLLOWING EXTRACTION.

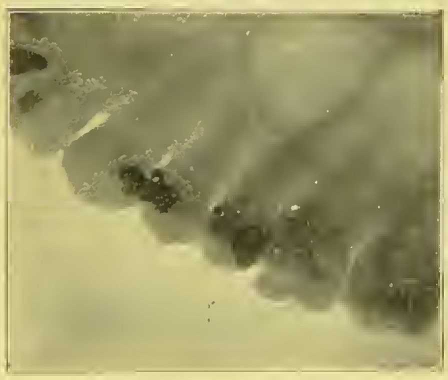

FIG. 196.—OUTLINE OF THE ANTRUM.

the tube, about one minute will be required and all intervening distances in a proportionate length of time.

It will be found in practice that about fifteen inches from the target is the proper distance and having once established a distance it should be kept as nearly as possible thereafter. There are so many variable conditions in the taking of a skiagraph, that those which can be fixed should be so.

When the distance has been settled upon, the dentist in determining the length of time has then to deal with but two variable conditions, the thickness of tissue and the condition of the tube. The thickness of tissue in dental cases does not vary as in general practice, and it is an easy matter to roughly estimate this factor. The following scale of the proportionate length of time as to the thickness of tissue may be established: If it is found that five seconds with a certain condition of tube will give a clear skiagraph of the lower incisors, it will require about eight seconds for the molars of the lower jaw and about fifteen seconds for the antral region of the upper, and all the other parts at proportionate lengths of time.

The condition of the tube has much to do with the length of time for an exposure. It will be found that the tube does not always begin at its highest efficiency, and it is this factor which is most variable and which will require the most careful consideration in timing the exposure. This cannot be determined by any standard, and the operator's skill, judgment, and experience are alone to be relied upon. During long exposures upon the thicker parts, the physician has an opportunity to

watch the tube through the fluoroscope and to judge as to the length of time, but the dentist, owing to the short time of the most of his exposures, must base his calculations upon the fluorescent appearance of the tube itself. For this reason it should be incidentally mentioned that darkening the room somewhat during the exposure will aid the dentist in judging of the working of the tube.

It should not be understood from what has just been said that the length of time in all X-ray work depends upon the two factors, thickness or density of tissue and the condition of the tube, for that is not the case. They are the ones, however, that are the chief factors in practical work. A more important consideration which determines the length of X-ray exposures is the instrument which is used for energizing the tube. However, when an operator confines his work to the use of but one form of energizing appliance, then this part of his calculations having been once made may be used practically as a fixed factor thereafter. This is especially true of the Rhumkorff coil when used to energize the tube. Although the output of the static machine may be modified somewhat by atmospheric conditions and the Tesla coil may indulge in an erratic performance, their characteristic lighting of the tube will prevail throughout the operation of the same. In a general way it may be stated that at the present state of perfection of X-ray appliances, the static machine requires three times as long and the Tesla coil twice as long a time as a Rhumkorff coil to produce the same effect upon a photographic plate. This comparison is based

upon appliances of the average capacity of its type of instrument. It is a well known fact that the best static machines do not give the volume of current that is produced by even a small Rhumkorff coil. They produce X-rays in the tube but not of sufficient volume to cause a marked effect in the length of time of the exposure. After a little experience the operator becomes familiar with these qualities of his generating appliance and by force of habit goes at once into the detail of the exposure, paying attention only to the thickness and density of tissue and the working of the tube.

The tube varies at different times, not only as to the volume of X-rays given off, but as to the condition of the vacuum. The length of the exposure, all other things being equal, has to do with the clearness of the picture, but the variation in the vacuum of the tube has to do with the contrast between the tissues of different density. The effect of tubes of different vacua is a most important consideration in X-ray work, for upon this depends almost entirely the securing of a good picture which will show the object or condition most clearly. A tube, for instance, which would best show a broken broach will give but an indistinct outline of the pulp canal or an abscess. X-ray tubes have therefore been classified according to the condition of their vacua into "soft," "medium," and "hard" tubes. The soft tube, if used in looking at the hand through the fluoroscope will show a dark outline of the whole hand and only by close inspection can the bones be distinguished. This is represented by an external shunt spark of about two and one half inches. The medium

FIG. 197.—LOW VACUUM, SHOWING FLESH AND BONE OF CHILD'S HAND.

vacuum is one, which if observed in the same way will show the bones with the strongest contrast if compared with the flesh. They appear black and on inspection their minute structure can be very easily seen and studied. The hard tube is one which will show the outline of the flesh and the bones within, but there is not that contrast between the two that was seen in the medium tube. The light seems to penetrate the two almost alike and because of the loss of contrast, the minute structure of the bone cannot be traced in its finer details as could be done with the medium vacuum.

The rays emanating from a soft tube have little penetrative power, whereas the rays from a hard tube have high penetrative power. For this reason the rays of the soft tube are affected by the least variation of the density of the softer tissues while those of the hard tube pass through all tissues with but slight change. It should be borne in mind that a photographic plate is more sensitive than the eye, so that in the taking of a skiagraph the vacuum should be much lower than would be necessary for the eye, and it is for this reason that a lower vacuum is employed for photography than for viewing the object through the fluoroscope. The vacuum, however, must be high enough in all cases for the rays to penetrate the subject. For this reason, also, it will be found that the degree of vacuum should vary somewhat in proportion to the thickness of tissue to be skiagraphed. It will require a little higher vacuum for the arm than for the hand, and a still higher vacuum for the pelvis. There is not only this rising scale of vacuum with increase of density and thickness which

FIG. 198.—MEDIUM VACUUM, SHOWING CONTRAST BETWEEN FLESH AND BONE, ALSO A BROKEN NEEDLE.

must be considered in the taking of every skiagraph, but the more important consideration of the proper vacuum for showing the object or tissue at its best advantage. The two must be considered together in calculating for the exposure. The physician is constantly dealing with tissues of a wide range of thickness and density, and only by constant practice is he able to successfully take every subject. While the dentist is more fortunate in this regard because his dental cases are nearly all of the same thickness and density, he, however, has a range of subjects which call for just as fine vacuum calculations. The degree of penetration necessary in dental cases is about equal to that met with by the physician in the case of the hand, so that having once found the proper vacuum for the average dental cases he has only to vary that slightly to get contrast or penetration. The average condition of vacuum necessary for dental cases will be found in a soft tube and at no time a higher vacuum than a medium tube.

There is a great variety of X-ray tubes upon the market and these are divided into two classes, namely, those with vacuum regulators and those without. The beginner, owing to the many details to be learned, should confine himself to the use of the latter class for here he is dealing with a fixed vacuum and that feature of his calculations may be omitted for the time being to be taken up later on when he is better prepared. The dentist should begin with two tubes, one of a soft and the other of a medium vacuum. These tubes are not only cheaper but they will later on be useful to him in another way, for in the course of time as their vacua rise by

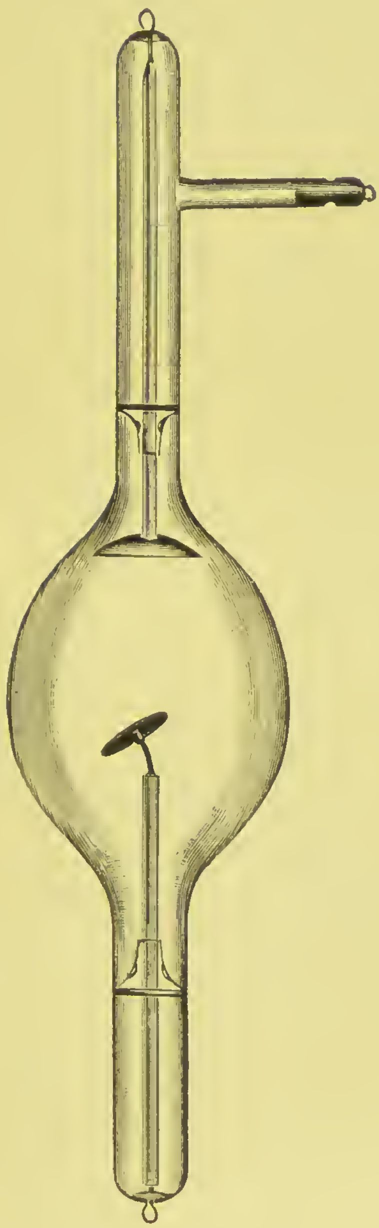

FIG. 199.—A. W. L. TUBE WITH VACUUM REGULATOR.

use, these tubes can be used for fluoroscopic examinations and for work upon the thicker parts. Another and very important reason for using a tube with a fixed vacuum for dental purposes is because of the very short time required in these cases. All tubes with regulating devices are at a normally high vacuum, and it takes a few moments of time to "work" them down; so that in practice it will be found that by the time the tube has been brought down to a condition of vacuum suitable for a dental case the film has been exposed long enough and it will be a chance result if the skiagraph is a good one. After the dentist has learned how to manage the tubes with vacuum regulators, he may be able to get the tube in condition and dexterously adjust the patient and film and use the tube before the vacuum rises, but this can never be as satisfactory as a tube with a fixed vacuum and in condition for immediate use.

Several methods have been devised for regulating the vacuum of X-ray tubes. One firm lowers the vacuum by introducing hydrogen intermolecularly into the bulb through a platinum tube sealed in one end. This form of regulator is shown in Fig. 199. Upon heating the platinum by either a flame or an electric current, hydrogen passes into the tube thus lowering the vacuum.

The most successful and practical method of regulating the vacuum is by means of the potash bulb. Queen & Company has upon the market one of the most satisfactory instruments of this kind. This is shown in Fig. 200. The main bulb has a small stem projecting therefrom. This stem contains a chemical which upon being heated by the passage of a current through an

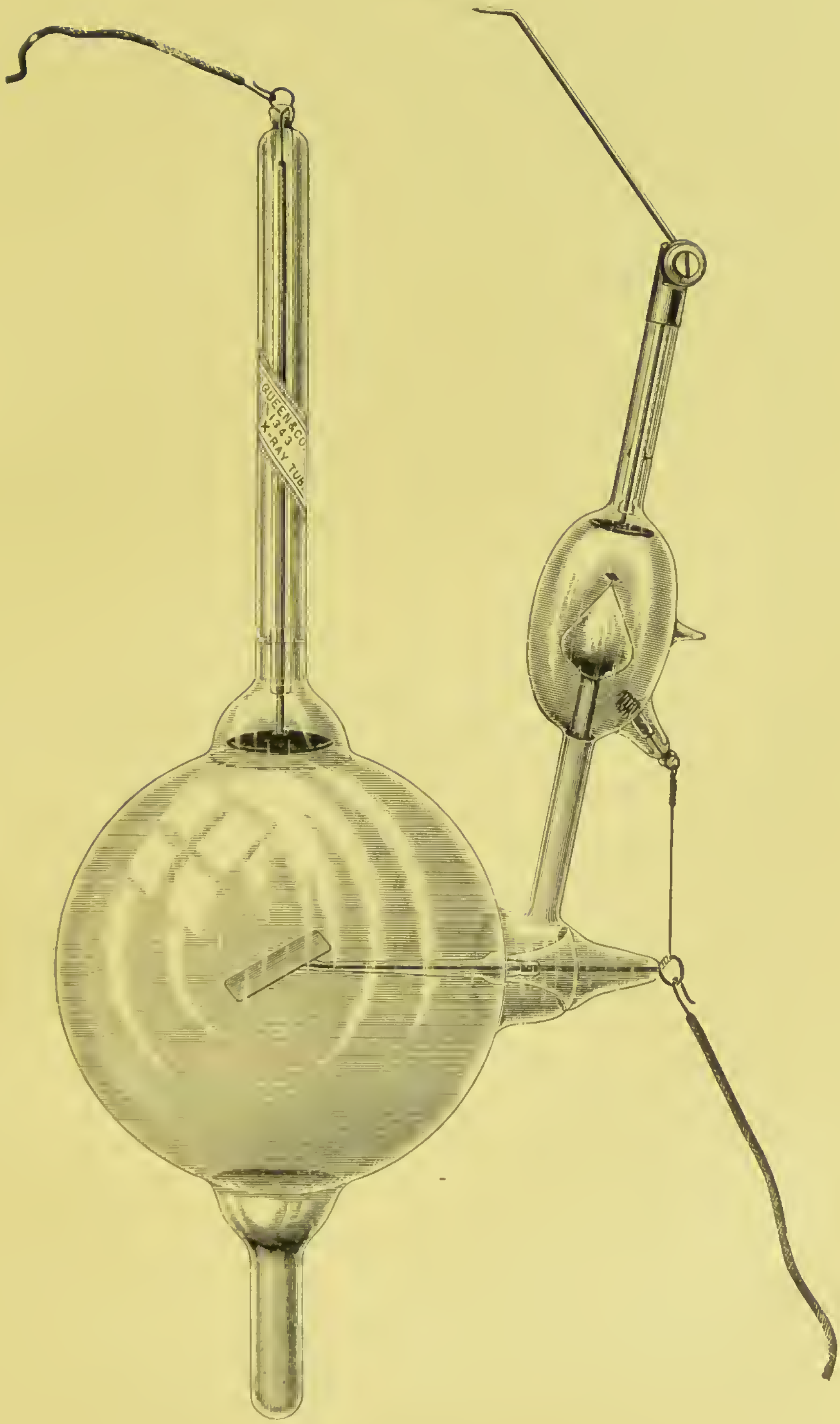

FIG. 200.—QUEEN SELF-REGULATING TUBE.

auxiliary bulb which surrounds the one containing the chemical, causes it to vaporize and this vapor passing into the main bulb lowers the vacuum. The chemical is reabsorbed upon cooling. This tube has been termed a self-regulating tube, because of the automatic adjustment that keeps up during its operation. A long finger pivoted upon the end of the regulating bulb can be brought within sparking distance of the cathode terminal outside of the tube. This distance as experience teaches will be proportionate to the degree of vacuum. A close adjustment will start and maintain a low vacuum while a wide adjustment will produce a high vacuum. The tube having been started at the required vacuum, it will be observed that there is a continual balancing of the resistance of the tube and the auxiliary path through the regulating bulb. When the vacuum rises as it naturally does during the action of the tube, unless so much current passes as to vaporize the electrodes and lower it in that manner, the current will take the path of less resistance through the auxiliary bulb. This will then vaporize sufficient of the chemical to lower the vacuum of the main bulb till it balances the resistance of the regulating circuit. This bulb with its regulating circuit acts much like a pair of scales. The degree of vacuum having been determined upon by the distance of the spark-gap, if the vacuum rises, that side of the scales becomes lighter and the chemical bulb upon the heavier side imparts its vapor to the lighter side till a balance has been reëstablished. This balancing is constantly going on and is so accurate

and at the same time so delicate that the change of vacuum can scarcely be detected in the fluoroscope.

The method of vacuum regulation as employed by the General Electric Company in its tubes is similar in action to the tube just mentioned, but has not the detail of construction which makes it a self-regulating tube. The chemical bulb is to be operated by the current passing through it and not by the heat of the current passing around it as with the Queen tube. For this reason it is not possible to make the regulating current a true shunt to the bulb and therefore a self-regulating tube.

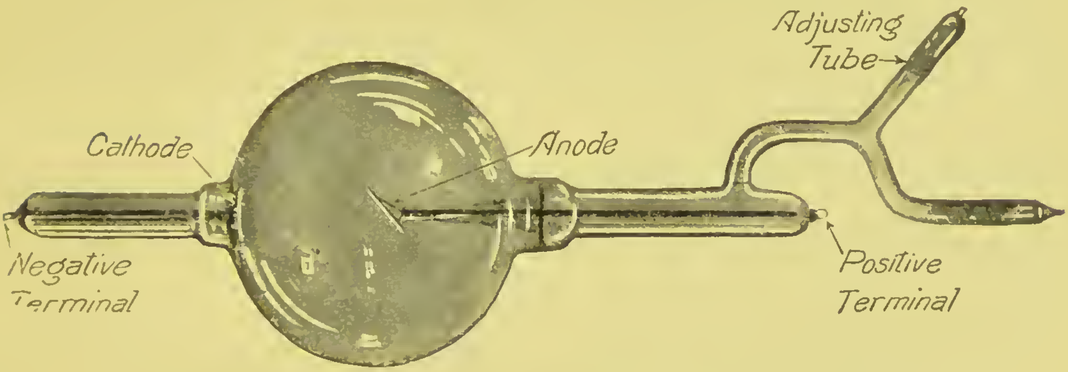

FIG. 201.—GENERAL ELECTRIC COMPANY'S TUBE WITH VACUUM REGULATOR.

The regulation of the vacuum can, however, be accomplished by hand in a very satisfactory manner, but in long operations requires constant watching. In order to simplify the regulation of this tube as much as possible, the author made an independent spark gap for his coil so that by the simple throwing of two points together the vacuum would be lowered. This device is also useful for other tubes and can be used with the Queen tube thus enabling the operator to manipulate the spark gap of the tube without jarring the same. A diagram of this is shown in Fig. 202.

An auxiliary set of spark-gap posts was adjusted upon the base of the coil about five inches from the main posts. The negative wire runs through the two posts at the end of the coil in series. The positive end is connected in the usual manner, and a wire connects the regulating stem of the tube with the other spark-gap post. By this device the operator by means of the second lever can in a moment's time reduce the vacuum to the desired de-

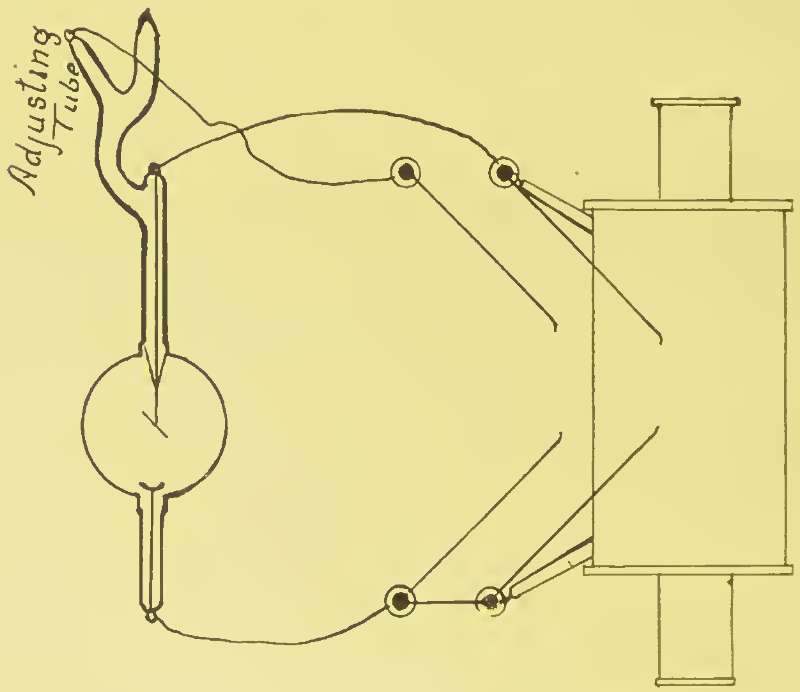

FIG. 202.—AUTHOR'S DEVICE FOR OPERATING VACUUM REGULATORS.

gree without any difficulty whatever and without any danger of going too far. If, during the running of the tube the vacuum rises, depression of the auxiliary lever will send a stream of sparks through the regulating stem which will lower the vacuum.

The definition of a radiograph is largely due to the

small area of the target. The smaller the target, the clearer will the radiograph be defined. With this object in view, many attempts have been made to use as small a target as possible and provide means for meeting the heat problem. The target becomes heated by the impact of the rays thereon to an extent that is proportionate to the volume of X-rays. In efficient tubes and coils the aim is, therefore, to use a heavy current upon as small a target as possible. Platinum is used in most tubes for target material because of its high fusing point, and even this is melted at times by an excess of current. An English tube has a target of osmium-iridium which has a much higher fusing point than pure platinum. This is practically infusible when used for target purposes. The alloy is found in nugget form and is held in a platinum matrix much like the setting of a diamond. The focus of the cathode disc is so well adjusted that the rays strike this nugget in an area scarcely larger than the head of a pin. This tube gives the best definition that has come within the experience of the author.

The firm of Oelling & Heinze has a tube upon the market as shown in Fig. 203, which has a very small target. A target of the same area with a current of even moderate amperage would become very hot. The makers have provided against this by mounting the target upon the end of a platinum pipe through which a stream of water is kept flowing during the operation of the tube. In this manner almost any volume of current may be used and at the same time the target is not injured thereby.

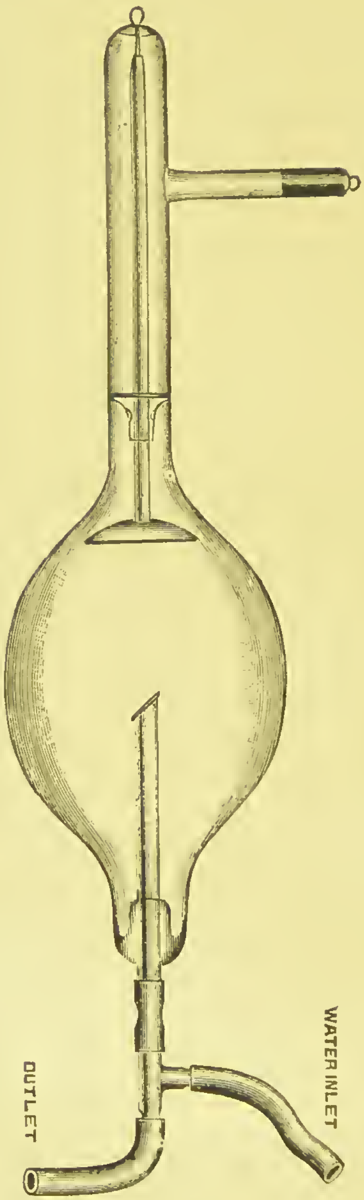

FIG. 203.—A. W. L. TUBE WITH COOLED TARGET.

When an alternating current is employed for energizing the X-ray tube a special design of tube and target is necessary for the highest efficiency. The current being alternating, if an ordinary tube and target is employed there will be a loss of half the X-rays. To meet this problem a double target was therefore designed. This as seen in Fig. 204 has two leaves of platinum at right angles to one another forming a wedge, and the whole is so poised with reference to the cathodal discs as to bring each leaf at an angle of forty-five degrees thereto. By this design and arrangement of the target all the rays are utilized and are projected in the same direction.

In making the connections for an X-ray tube, care should be observed that the platinum loops are not bent or broken, and for this purpose ordinary fine lead wire such as is used for fuse purposes has been recommended. This wire is soft and can easily be fastened to the platinum loops without any danger to the latter.

The blackening of tubes which comes from extensive use can be prevented to some extent by introducing two small spark gaps one in each of the two wires connecting to the tube proper. A neat spark gap can be easily made by using a three-inch piece of glass tubing such as is used for water gauge purposes, and enclosing the ends with metallic thimbles through which project two points about three-quarters of an inch in length. This leaves a spark gap of about an inch and a half in length on either side of the tube. These gaps should be permanently attached to the tops of the main spark-gap posts and the lead wire from the tube attached to their

outer ends. When these spark gaps are in place, the current passes through them in going to and returning from the tube, and their total length of spark should be subtracted from that produced by the main spark gap, when measuring the parallel spark which about equals the resistance of the tube.

During the first years following the discovery of the X-ray, many people were burned during the exposures. This trouble did not appear until some two or three weeks following. Many things had to be learned both as to the nature of the X-ray and the details of manipulation. It is not the X-ray itself that causes the burn, but electric conditions surrounding the tube. The methods of exposing have changed, the instruments have been improved, and preventives have been found for this trouble. If the exposures are long ones and for certain reasons are to be repeated, it is found to be a safe procedure to allow about three weeks to lapse between exposures in order that the effect may pass away. The efficiency of the instruments has also been so much improved that the length of time has been materially lessened. As preventives of the burning effect, a covering of vaseline or any thick oil upon the part exposed has been recommended and successfully used; or a sheet of pasteboard covered with aluminum foil and grounded, if placed between the patient and the tube, will carry off this current. The latter method is more convenient and most generally used. The patient may also be protected by a sheet of rubber. While the agents just mentioned are to be interposed between the tube and the patient, they

Fig. 204.—Thomson Double Focus Tube for Alternating Current.

do not materially effect the strength of the X-ray. Dr. Kinraide, supposing the X-ray dermatitis to be due to the formation of nitrous acid in the tissues, recommends the immediate washing of the field of exposure with a strong solution of bicarbonate of soda or any alkaline wash.

The film or plate having been exposed, the next step is its development. For this purpose a dark-room is necessary. This need not be very large but it must be perfectly dark and have running water or a large vessel from which a small stream can be drawn. The dark-room for X-ray work must be somewhat darker than for general photographic purposes. The developing light should have at least two plates of red and one of orange-colored glass, and to get the best effect the plates should not be continually exposed to this light during development. The plate can be held above the light and occasionally lowered to see how the development is progressing.

There are two steps in the development of a negative, the developing and the fixing, and for this reason two sets of trays of different material should be employed, one set for the developer and the other for the fixing solutions. The greatest care must always be observed that these trays are kept clean and free from other chemicals, for the least trace of hyposulphite of sodium, or "hypo" as the fixing solution is commonly called, in the developer will spoil the effect. For the development of dental films the author uses an ordinary porcelain teacup. It will be found that the film is too small to handle conveniently without destroying the edges in its

manipulation, if an attempt is made to keep it straight. Enough developer is prepared to more than cover the film and this is continually shaken during the development. Occasionally the film is taken out and examined to see how the development is progressing.

There are a great many formulas for the developing solution. One of the most popular developers is Rodinol. This requires only to be diluted with water, in the proportions of about one of Rodinol to fifteen of water. This developer is better for dental cases for it does not soil the fingers as some solutions will do, and it can be used over again.

Still another developer is made up as follows:

Eikonogen	1 oz.
Water (hot)	29 oz.
Sulphite of Soda (crystals)	1½ oz.
Carbonate of Potash	1 oz.

Mix all in a granite iron vessel and when cool put in a well-stoppered bottle.

This solution is to be used without dilution and can be used over again as it improves with a little use, but in time becomes exhausted and badly discolored.

The most popular among professional photographers is the "pyro" developer, composed as follows:

ACID SOLUTION.

Water	16 oz.
Sulphite of Soda (crystals)	4 oz.
Pyrogallic Acid	1 oz.
Sulphuric Acid	10 drops.

ALKALINE SOLUTION.

Water	16 oz.
Carbonate of Soda	4 oz.

TO DEVELOP, TAKE OF

Acid Solution	1 oz.
Alkaline Solution	1 oz.
Water	8 oz.

This should be made up in two bottles for stock solu-

tion. It should be mixed at the time of using and then thrown away as it cannot be used a second time if allowed to stand. For dental cases a one-ounce graduate if used for measuring will be found to be the most convenient. Use one drachm of each solution and then fill the graduate full of water. It will be found that nearly all one-ounce graduates will hold about two drachms over an ounce.

Of the above we would prefer either the pyro or the Eikonogen for plates and the Rodinol for dental films.

Before the plate is put in the developer it should be washed in running water during which time the fingers are run over it lightly to remove any particles of dust. The plate by being first wet also takes up the developer more evenly. It is then put in the tray and the developing solution poured over it as quickly and evenly as possible. The films of dental cases need not be washed and the fingers should never touch the sensitive side before it reaches the developer.

No part of the photographic routine is so important as the development of the picture. There are many things to be learned and the most of these can only be found out by experience. Only general instructions can be given, and it must be left to the operator to work out in his own way by practical experience the finer details of this process. He has to learn not only how to develop properly exposed pictures, but he must learn the indications of an over- or an under-exposed picture and be able to treat it accordingly. In X-ray work the operator has always to deal with a picture which has not as much contrast as a photo-

graph of a person or a landscape, and he has therefore a difficult picture to develop. Furthermore, the development of an X-ray picture often calls for the development for a certain thing. It may be to get a broken broach, or it may be to get the outlines of an abscess in the boldest relief.

The next step is the fixing of the negative. For this purpose hyposulphite of soda is used by nearly all photographers. It is generally spoken of as the hypo solution and is prepared by taking four ounces of hyposulphite of soda to thirty-two ounces of water. The negative after being developed is washed in running water and is allowed to remain in the fixing bath till the back of the negative is entirely cleared. It is then ready for the final washing which should be at least thirty minutes in running water or in frequent changes of water.

The negative, if a glass plate, is then put upon edge to dry. If it is a film it should be immersed for five minutes in a weak glycerine solution one half ounce of glycerine to thirty-two of water to prevent curling after drying. The film is then placed upon a board celluloid side down and fastened by a pin in each corner. Experience has shown that if the negative is placed in a breeze or before an electric fan that it will take but a short time to dry. The quick drying of the negative is not only of advantage by reason of the time that it saves, but it also produces a thin negative, or one from which a print can be quickly obtained.

When the negative is dry this part of the work is complete. Many X-ray operators prefer to study the nega-

tive of a case but sometimes it is desirable to have a print from it, and owing to the difficulties and the expense necessary, unless the operator has a liking for it he had much better send the negative to a photographer for the print. This can usually be had at small expense and he is relieved of much worry. If the operator desires, however, to print his own pictures, he must buy a printing frame and another set of trays. After rather unsatisfactory attempts at all methods of toning, as the process of fixing the print is called, the author has arrived at the conclusion that the most practical method is to use solio paper with its special toning solution for large subjects and velox or almost any of the quick-toning papers for dental cases. The latter class of papers give a great deal of contrast and are also very easily managed. The amount of care that is necessary in toning a picture by the best methods as employed by professional photographers is too exacting for the practical printing of X-ray pictures except those of large subjects. In dental cases the subject is small and much more contrast will be allowable than when printing a large subject. It would therefore be recommended that the self-toning papers as they are called. be used in dental cases for they save time, can be printed by gas light, and require a simple method of development and fixing.

CHAPTER XII.

An Independent Plant.

While the commercial applications of electricity are constantly increasing and the plants for meeting the growing demands are keeping pace with them, many dentists will still not have access to a commercial current. Moreover, the dentists in small towns who do have access to a commercial current, usually find such a current to be either an alternating current of fifty-two or one hundred and four volts, or the five hundred volt current of a car line, none of which are the best currents for dental purposes. To meet all the dental requirements, a person in this position must establish an independent plant. At first thought this may appear to be a formidable undertaking, but the author having established one of his own for experimental purposes, finds it to be entirely feasible, and one which will give a satisfactory return for the time and money invested.

An independent plant such as will be described, while especially designed for dental purposes, will be found to be of use in many other ways. The majority of suburban dentists have their offices in their homes, and this plant will be of ample capacity for also supplying his living apartments with electricity, which will be more than equal to a city current. He may use it for light, for fans, for cooking, for charging an automobile, and in

fact for all, and perhaps more, purposes than a single commercial current would be able to supply.

While the engine is charging a storage battery, it may also be operating the laundry, and many household utensils. In fact, the owner of such a plant will be surprised at the many applications that can be made of mechanical power in the home. The introduction of power and electricity in the country place is an innovation especially welcomed by the feminine section of the household, for it relieves washday and ironing day of the toil and drudgery which has characterized this day as "blue" Monday. The laundry washer and the electric iron may be operated either by the engine and dynamo direct, or by power from the storage battery.

In the practical operation of such a plant, a given day once or twice a week is set apart for charging the storage battery, at which time other office and household operations are arranged for. If, however, the storage-battery part of the plant is of sufficient capacity, all the power and other electrical applications can be made from that irrespective of the operation of the engine.

An independent plant consists of an engine and dynamo, and to be complete and convenient, a storage battery should also be used. A gas-engine is used because of its small size, low cost, and simplicity of operation. As a rule, most gas-engines can be operated by gas or gasoline, interchangeably, so that if the dentist has not the one he may use the other. As a matter of fact, although not quite so convenient, the output of a gas engine is considerably more when operated by gasoline, than when operated by either natural or artificial gas.

There are two types of gas-engines, the horizontal, and the upright. The horizontal, as illustrated in Fig. 205, has its cylinder in the horizontal position. This position is employed in all large engines, and permits of perfect lubrication of the piston, which is an important feature. The cylinder and bed is a single casting in the small sizes, and the latter is provided with holes for firmly bolting to the foundation.

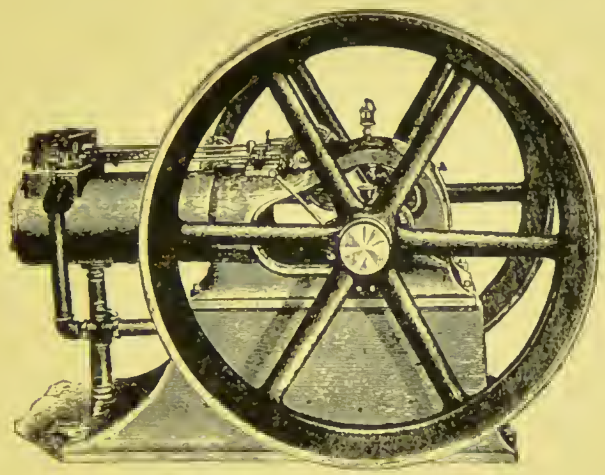

FIG. 205.—HORIZONTAL GAS ENGINE.

The upright engine as shown in Fig. 206, has its cylinder in an upright position. This form is frequently employed in engines of ten horse-power, or less, and its principal advantage is the vertical motion of the reciprocating parts. Moreover, the jar of the explosion is received by the base in a downward direction upon the foundation, which reduces the motion of the engine to a minimum. No matter how well balanced a horizontal engine may be, and how well it may be seated on its foundation, there will always be some movement and jar from the explosion.

The working principle is the same in both styles of engines, the principal difference being the position in which the cylinder is placed. The motive power is given by the explosion of a gas, properly mixed with air. Every dentist has observed that if in lighting the gas burner under his vulcanizer, he does not introduce the flame before turning on the gas, a slight explosion will

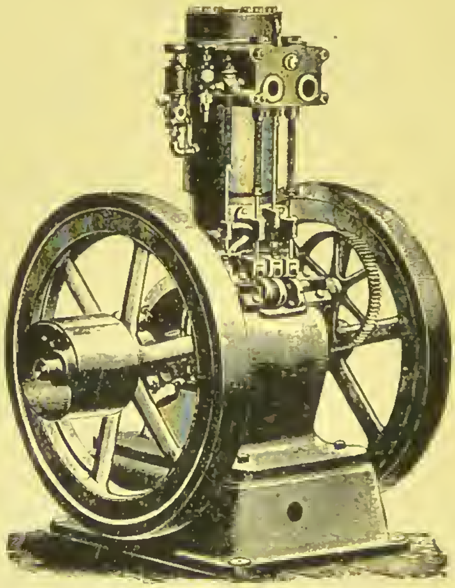

FIG. 206.—UPRIGHT ENGINE.

take place. The intensity of this explosion varies according to the proportions of air and gas. This is precisely what takes place in the gas-engine. Gas or vaporized gasoline, properly mixed with air, is introduced into the cylinder, and this is ignited at the proper moment by an electric spark, or by the heat of the hot tube. The explosion takes place when the piston is at the bottom of the cylinder, and the force of the explosion drives the piston to the other end of the cylinder. This motion

is communicated by the usual means of a connecting rod to the crank shaft and balance wheel.

The cylinder of the gas-engine has only one head. In a steam-engine the steam is introduced at both ends of the cylinder, but in the gas-engine only at the farther end. This allows of very short coupling, and explains the compact construction of the gas-engine, when compared with the steam-engine. The piston is usually half again as long as its diameter, in order that it may not cramp in the cylinder when the connecting rod is in its most angular position. To prevent the cylinder from becoming overheated, it is covered with an outer jacket, through which water is kept in constant circulation. In very small engines the cylinder is kept sufficiently cool by outstanding ribs, which radiate the heat.

The mode of operation in most gas-engines is as follows: Beginning with an outward stroke, the gas and air of the proper proportions is drawn into the cylinder. Upon the return stroke the gas is ignited just as the piston about reaches the lower end of the cylinder. This is the moment at which the impulse is received, and the piston is driven out by the force of the explosion. Upon the return of the piston the burnt gas is forced out through an exhaust port, which is opened by a cam appliance at the proper moment.

This completes the cycle, and it will be seen that the piston makes two complete out and in movements to each explosive impulse. In other words, the balance wheels make two revolutions to one explosion in the process of taking in, exploding, and exhausting the gas. There are some engines, especially in the upright types

in which an explosion is produced with each outward stroke of the piston, but these are not the most efficient.

The proportions of air and gas for the most powerful explosions vary with the kind of gas employed, but the average proportions are about one of gas to ten of air. If gasoline is used, a small jet of this is admitted through a needle valve to an air chamber where it volatilizes and mixes with the proper proportions of air.

There are two methods of igniting the gas, one by an electric spark, and the other by a hot tube. When the electric spark is employed it may be produced in two ways: One by the simple opening of the circuit of an electric current, and the other by the use of an induction coil which causes the spark to jump from one point to another which is not quite in contact with it. If the contact method is employed, two or three cells of the Edison-Lelande type are usually necessary, and the current passes through a spark coil. This is simply a coil of rather heavy wire, wound around a bundle of soft iron wires. The effect of the spark coil is to cause the current to exhibit itself in a large spark when the circuit is broken. This is due to the inductive effect caused by the soft iron core of the coil. The jump spark is produced in the same manner that a spark is produced in a Rhumkorff coil. The terminals of the secondary are poised at a short distance from one another, and at the proper moment a spark is caused to pass between them.

The hot-tube method of ignition consists of a small tube sealed at its outer end and which communicates with the gas chamber, at the bottom of the cylinder.

This is brought to a red heat at its outer end by means of a Bunsen burner. In the operation of the hot tube, the mixed gas is forced into this tube by the pressure caused by the piston as it reaches the inner end of the stroke. The length of the tube is so proportioned that the gas, in its compression, does not reach the igniting heat until the piston is at the proper position. When the right proportions of gas and air are forced into this tube, they become ignited by its heat and the explosion takes place.

The exact moment of ignition is an important matter. In starting the engine the explosion should not occur till the crank has passed the dead center, but as the speed increases the ignition should take place a little before the dead center is reached. This is accomplished by shifting the position of the cam in the electric sparker, or by raising the heat of the tube when the hot tube is used.

The regulation of gas-engines is accomplished either by choking the supply of gas, or by entirely cutting off an occasional charge. The former is accomplished by operating a wedge-shaped piece of metal under the gas valve, from the governor on the engine. The method of regulating on the "hit or miss" plan is accomplished by a trip appliance, which either opens the valve to the limit, or does not open at all. The former method produces a more uniform speed of the engine, which is necessary when operating a dynamo.

In selecting a gas-engine for our plant it should be a nominal three horse-power. The actual amount of work to be gotten from such a machine will seldom ex-

ceed two horse-power. There are but few gas-engines which give the rated horse-power, even under the most favorable conditions. Moreover there are several reasons for having one as large as this. The actual electrical horse-power necessary for the heaviest requirements in dental practice is about two. By the time the mechanical energy of the gas-engine has been converted into electrical energy through the dynamo, there will be but a small margin left. Moreover a small gas-engine is difficult to regulate, and when loaded to the limit it becomes very unsteady. This is especially noticeable if electric lamps are operated from the dynamo direct. The jar of the engine is very slight when it is not overloaded, for this reason its life will be preserved and at the same time it will be a comparatively quiet piece of machinery. It is a common fault to find the gas-engine in all its applications continually overloaded.

One might suppose that a large engine would be more expensive to operate than a smaller one, but it is a well known fact that a small engine overloaded, consumes more gas than a larger one would with the same load. For this reason there is no economy in using a small engine which is constantly working at its limit.

The cost of a three horse-power is but little more than a two horse-power engine. The usual prices are as follows: One horse-power, one hundred dollars; two horse-power, one hundred and fifty dollars; and a three horse-power, one hundred and seventy-five dollars. There are some upright three horse-power engines

which are listed at one hundred and twenty-five dollars, which will give excellent results.

The dynamo of our plant should be a fifteen or twenty-light machine. This, if rated in "kilowatts" would be about a one-kilowatt dynamo. It should be compound wound for the purpose of compensating to a small extent for the fluctuations in the load that will be put upon it and also for any variation in the speed of the engine. The author's as illustrated in Fig. 207

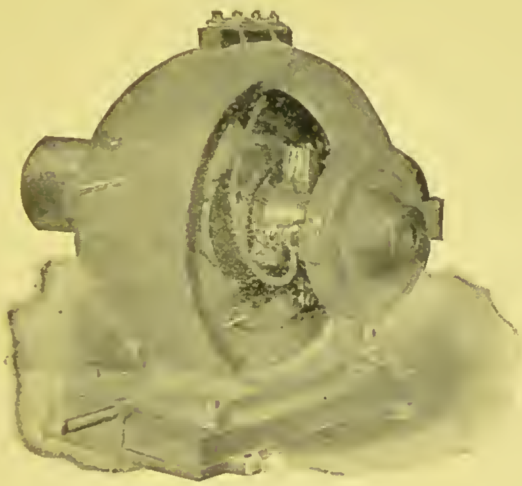

FIG. 207.—COMPOUND WOUND DYNAMO.

is made by Roth Brothers, of Chicago, is a compound wound of one kilowatt capacity, costing eighty-five dollars.

It is wound for one hundred and ten volts, which would be recommended for the following reasons: This voltage is standard, it is the ideal dental current, the majority of dental instruments are designed for this voltage, and electrical fittings for it can always be had. This dynamo has given the best of satisfaction. Even when carrying twenty lights it does not heat to an ap-

preciable extent. It can be made dust proof by enclosing the ends with plates, which are made to fit the openings. The bearings are continually oiled by the ring method, so satisfactory in all large machines. The base is provided with a sliding device, whereby the dynamo can be easily moved for the purpose of tightening the belt.

The switch-board of our plant should be arranged as diagrammed in Fig. 208. Four wires will run from the

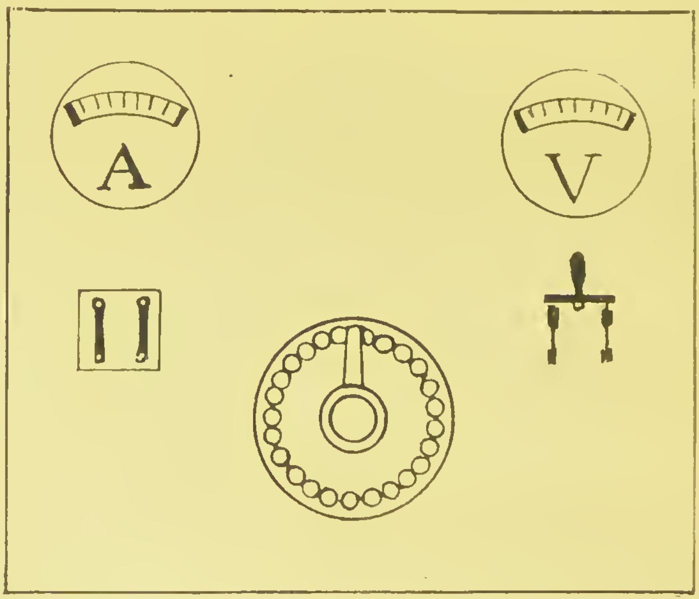

FIG. 208.—SWITCH-BOARD.

dynamo to the board. Two of them will connect to the rheostat for regulating the voltage, and the other two are the mains which first run through the fuse block, and then to the knife switch. The volt meter which is connected across the mains, is always a necessary adjunct. The ammeter, while not a necessity, is a satisfactory instrument to have. This is to be placed in

series on one side of the main wires. It tells the exact amount of current that is being used and in conjunction with the volt meter one can estimate the output of the plant at a glance.

The gas-engine and dynamo should be placed on the ground floor of the house or cellar, provided the latter is dry, or, it may be placed in an out-building. If it should be in an inconvenient place the switch-board may be put at any point in the house that will be convenient, for the dynamo can be regulated just as well at some distance from it, it being only necessary to run four wires from the dynamo to the switch-board. The engine and dynamo of the author's plant are in the cellar and the switch-board is in the library. The starting of the engine can be done in a moment's time, and it requires no attention till it is to be shut off. This could also be done from the switch-board, were it necessary.

While the gas-engine and dynamo are the necessary parts of an independent plant, such an arrangement would not be practical unless there was constant use for current during its operation. In the practice of dentistry, hours sometimes elapse without using current, during which time there would be an unnecessary waste of energy. Frequently there is use for the current for a short period for which it would be impracticable to start the engine each time.

To meet the intermittent use of current, a supply should always be "on tap" as it were. To this end a storage battery is necessary and when once installed places the dentist in an independent position, and at the same time makes his plant a most practical venture.

The storage battery should be one of fifty-five cells. These need be of only thirty ampere-hours' capacity. Such a battery would operate a sixteen candle-power lamp for sixty hours, or ten such lamps for six hours, which would be sufficient to light a medium-sized house in the evenings for a week during the summer months. In the winter, however, about twice the amount would be consumed, and it would be necessary to operate the plant twice during the week. If our plant were to be operated at fifty-five volts' pressure, then half the number of cells would be necessary, but they should be of twice the ampere capacity to give the same output. So it will be seen that there is very little economy in the operation of the plant at fifty-five volts. This may be done, however, in isolated plants intended for lighting purposes only, but where dental instruments are to be operated by it, the higher voltage is preferable.

The type of storage cell for this purpose is not material, however, in point of cheapness, the "High Tension" cell as described in the chapter on the storage battery, can be recommended. Four boxes of these trays will give one hundred and twelve volts. Their simplicity of construction and compact bulk are desirable features. Moreover, when these cells are used it is just as economical to operate at one hundred and twelve volts as at fifty-five. If the above type of cell be adopted, the use of the forty ampere hour cell, rather than the thirty ampere hour cell would be recommended, for the reason that the first cost is but little more comparatively, the care is the same, the capacity is greater, and the life will be much prolonged.

In setting up these cells, they should have the outside boxing removed, and then be placed on a table or rack in such a manner that all the edges can be easily seen. The edges of the trays should be carefully separated, so that each one is equally distant from its neighbors. The electrolyte, consisting of four parts of rain water to one of commercial sulphuric acid, should be mixed in earthenware jars, by adding the acid to the water. When this is cold, the absorbent material between each tray is to be filled till it will take up no more. The best method of doing this is to use a rubber syringe bulb, with a hard rubber point, such as can be found at the drug stores. The solution should be added from time to time and in sufficient quantity to show around the edges. The trays must also be kept level, so as to insure complete covering of both sides of each plate, with the electrolyte.

In the practical operation of the plant with the storage battery the dynamo should be operated at about one hundred and twenty-five volts when charging the battery, and a current of about ten amperes for the forty ampere hour cell will be sufficient. This size of battery can be charged in half a day and such a charge will last from three days to a week, according to the use put upon it. If the dentist uses a laboratory, and an engine motor, a gold annealer and the usual amount of light for his office, such a charge should last a week. If in addition he uses an electric oven, an air compressor, and cautery, his battery will require charging twice a week.

American or B. & S. Wire Gauge.	New British or Standard Wire Gauge.	Decimal Gauge in Mils.	Cross Section in Circular Mils. (Cir. Mils. = .7854 Sq. Mils.)
....	0	....	104976
....	1	300	90000
1	....	....	83694
....	2	....	76176
....	....	275	75625
2	....	....	66373
....	3	....	63504
....	....	250	62500
....	4	....	53824
3	....	....	52634
....	....	225	50625
....	5	....	44944
4	....	....	41743
....	....	200	40000
....	6	....	36864
5	....	....	33102
....	....	180	32400
....	7	....	30976
6	....	....	26250
....	8	160	25600
7	....	....	20820
....	9	....	20736
....	....	140	19600
....	....	130	16900
8	....	....	16510
....	10	....	16384
....	....	120	14400
....	11	....	13456
9	....	....	13092
....	....	110	12100
....	12	....	10816
10	....	....	10384
....	....	100	10000
....	13	....	8464
11	....	....	8234
....	....	90	8100
12	....	....	6530
....	14	80	6400
....	15	....	5184
13	....	....	5179
....	....	70	4900
14	....	....	4107
....	16	....	4096
....	....	60	3600
15	....	....	3257
....	17	....	3136
16	....	....	2583
....	....	50	2500
....	18	....	2304
17	....	....	2048
....	....	45	2025
18	....	....	1624
....	19	40	1600
....	20	....	1296
19	....	....	1288
....	....	35	1225
....	21	....	1024
20	....	....	1022
....	....	30	900
21	....	....	810.1

American or B. & S. Wire Gauge.	New British or Standard Wire Gauge.	Decimal Gauge in Mils.	Cross Section in Circular Mils. (Cir. Mils. = .7854 Sq. Mils.)
....	22	28	784.0
....	....	26	676.0
22	....	....	642.5
....	23	24	576.0
23	....	....	509.5
....	24	22	484.0
24	....	....	404.1
....	25	20	400.0
....	26	18	324 0
25	....	....	320.4
....	27	....	269.0
....	....	16	256.0
26	....	....	254.1
....	....	15	225.0
....	28	....	219.0
27	....	....	201.5
....	....	14	196.0
....	29	....	185.0
....	....	13	169.0
28	....	....	159.8
....	30	....	153..8
....	....	12	144.0
....	31	....	134.6
29	....	....	126.7
....	....	11	121.0
....	32	....	116.6
30	....	....	100.5
....	33	10	100.0
....	34	....	84.64
....	....	9	81.00
31	....	....	79.70
....	35	....	70.56
....	....	8	64.00
32	....	....	63.20
....	36	....	57 76
33	....	....	50.13
....	....	7	49.00
....	37	....	46.24
34	....	....	39.75
....	38	6	36.00
35	....	....	31.53
....	39	....	27.04
36	....	5	25.00
....	40	....	23.04
37	....	....	19.83
....	41	....	19.36
....	42	4	16.00
38	....	....	15.72
....	43	....	12.96
39	....	....	12.47
....	44	....	10.24
40	....	....	9.888
....	....	3	9.000
....	45	....	7.840
....	46	....	5.760
....	47	2	4.000
....	48	....	2.560
....	49	....	1.440
....	50	1	1.000

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